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Effect of a Dynamic Keyboard and Word Prediction Systems on Text Input Speed in Patients with Functional Tetraplegia

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Effect of a Dynamic Keyboard and Word Prediction Systems on Text Input Speed in Patients with Functional Tetraplegia

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Keywords:	Assistive technology, Computer, Dynamic keyboard, Learning, Satisfaction, Text input speed, Quadriplegia, Self help devices, Virtual Keyboard, Word prediction

17/12/2012

Dear Sir/Madam,

Please find attached the revised version of our manuscript entitled: **“Effect of a Dynamic Keyboard and Word Prediction System on Text Input Speed in Participants with Tetraplegia”**

We have replied to all the reviewers’ comments and have substantially modified the text. We hope that you and the reviewers now find the manuscript suitable for publication in Journal of Rehabilitation Research and Development.

Yours sincerely,

Samuel POUPLIN, Johanna ROBERTSON, Djamel BENSMAIL

**TITLE : Effect of a Dynamic Keyboard and Word Prediction Systems on Text Input
Speed in Participants with Functional Tetraplegia**

SHORT TITLE: Effect of Prediction System on Text Input Speed.

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10
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12 **Statement of responsibility :**

13
14 Samuel POUPLIN, participated in the conception and design of the protocol, analysis and
15
16 interpretation of data and drafting the article. Justine BOUTEILLE participated in the
17
18 conception and design of the protocol. ,Johanna ROBERTSON participated in the analysis
19
20 and interpretation of data and drafting the article. Jean-Yves ANTOINE, programmed Sybille
21
22 software and helped to draft the article, Antoine BLANCHET, Jean Loup KAHLOUN, and
23
24 Philippe VOLLE programmed CVK software. Frédéric LOFASO helped to draft the article,
25
26 Djamel BENSMAIL participated in the analysis and interpretation of data and drafting the
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28 article.
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ABSTRACT

Purpose: Information technology plays a large role in both the social and the professional lives of individuals. Text input is often slow with assistive devices which provide computer access to disabled people. The aim of this study was to evaluate the effect of a dynamic on-screen keyboard (Custom Virtual Keyboard, CVK) and a word prediction system (Sybille) on text input speed in participants with functional tetraplegia.

Method: 10 participants tested four modes at home (static on-screen keyboard with and without word prediction and dynamic on-screen keyboard with and without word prediction) for 1 month before choosing one mode and using it for another month.

Results: The dynamic keyboard reduced text input speed compared with the standard keyboard and the addition of word prediction had no effect on text input speed.

Conclusions: This study raises many questions regarding the indications for specific assistive devices and software, as well as the optimal ergonomic design of dynamic keyboards and the number and position of words that should be predicted. The development of the CVK is continuing, and future studies will aim to address these questions in larger numbers of participants.

1
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3 **KEY WORDS:** Assistive technology. Computer. Dynamic Keyboard. Learning. Satisfaction.
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5 Quadriplegia. Self-help devices. Text Input Speed. Virtual Keyboard. Word Prediction
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7 System.
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10 11 **ABREVIATIONS**

12
13
14
15
16 CVK : Custom Virtual Keyboard
17

18 19 20 **ACKNOWLEDGMENTS**

21
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26 of this project.
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1 Introduction

Computers now play an important role in the lives of most individuals. They are used for recreational purposes (e.g. multimedia and games), work, and communication (internet, email, instant messages) (Bigot [1]). Access to the computer is crucial for disabled people and may improve their quality of life (Boonzaier [2]). The use of computers can facilitate mainstreaming at school, for example, and the Internet may provide a valuable means of communication (Picard [3]) (ANLH [4]). However, the use of computers requires a certain degree of motor ability. People with motor disabilities frequently experience difficulties in using pointing input systems (mouse to displace an on-screen cursor) and also with inputting text (via a keyboard). Many solutions exist to facilitate computer access, depending on the patient's specific impairments and the purpose for which the computer is used (Devries [5]), (Chen [6]), (Lopresti [7]), (Pouplin [8]). The most common solution relies on the use of a virtual keyboard which is directly displayed on the computer screen. The selection of the desired key on the virtual keyboard can be handled by a large variety of input devices, from a microgravity mouse to single switch devices supplemented by a process of dynamic scanning of the keyboard.

Although such assistive devices render computers accessible to disabled people, the actual inputting of text can be very slow. Over the past few years, attempts have been made to develop systems to improve text input speed.

One method is to optimise the layout of the keys on the keyboard (Dvorak [9]). Several studies have shown that altering the layout of static onscreen keyboards, based or not on bigrams of words reduces the number of movements necessary when using pointing devices or the number of selections by switches (MacKenzie,[10]) (Raynal, [11]) (Leshner, [12]) (Schadle, [13]). In all cases, the effect on text input speed remains limited.

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3 26 Ambiguous and dynamic keyboards have been developed to increase text input speed.
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5 27 Ambiguous keyboards combine several letters on the same key, for example as on mobile
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7 28 telephones (Kushler, [14]) (Leshner, [15]). Dynamic keyboards alter the layout of the keyboard
8
9 29 at each keypress so that the characters most likely to follow are positioned around the one
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11 30 which has just been typed (Ward, [16]) (Heckathorne [17]). Both these keyboards have been
12
13 31 shown to reduce the number of key selections necessary or the latency between two selections
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15 32 for people using scanning devices (Harbush, [18]) and the displacement of the cursor for
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17 33 people using pointing devices (Merlin [19]). However, very few studies have evaluated the
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19 34 effect of such keyboards on text input speed in participants with motor disability over a long
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21 35 duration.
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25 36 Another method to increase text input speed is to display words which are predicted
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27 37 from the letters previously typed. Word prediction reduces the number of necessary key
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29 38 strokes by avoiding having to type the whole word. Higginbotham found keystroke savings
30
31 39 of 40-50% (Higginbotham [20]) in healthy subjects using word prediction in 5 different types
32
33 40 of communication software for disabled people, available on the market, however the effect
34
35 41 on text input speed is uncertain and results in the literature are inconclusive (Koester [21]
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37 42 (Anson, [22]) (Koester [23]) (Koester [24]).
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41 43 The aim of this study was to carry out a preliminary evaluation of a dynamic on-screen
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43 44 keyboard and a word prediction system (Custom Virtual Keyboard, CVK) on text input speed
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45 45 in participants with functional tetraplegia, using the systems over a period of 2 months at
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47 46 home. The Custom Virtual Keyboard (CVK) was developed by our team and is available free
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49 47 of charge (Figure n°1).
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52 48 We hypothesized that both word prediction and the dynamic keyboard would increase
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54 49 text input speed and thus the combination of both systems would further increase text input
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56 50 speed.
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5 52 **Method**6
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10 54 **Participants**

11 Participants with functional tetraplegia followed-up at the Physical Medicine and
12 Rehabilitation department of the Raymond Poincaré Teaching Hospital (Garches, France)
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14 between 2005 and 2010 were contacted by telephone to determine whether they fulfilled the
15
16 inclusion criteria and wished to participate. Participants were included if they were over 18
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18 years old, had functional tetraplegia (e.g. due to locked-in syndrome, myopathy, or cervical
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20 spinal cord injury), regularly used an on-screen static AZERTY keyboard based on a PC
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22 computer with Windows (the only operating system that can accommodate the CVK at
23
24 present) and who were not regular users of dynamic keyboards or word prediction.
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29 Participants had home access to the internet, and lived in or near Paris, France. Participants
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31 were excluded if they had cognitive, linguistic or visual impairments preventing the use of a
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33 computer.
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39 67 **Material**

40 This study was carried on the CVK (Custom Virtual Keyboard), which was developed
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42 by our team and is available as open source software (Figure n°1).
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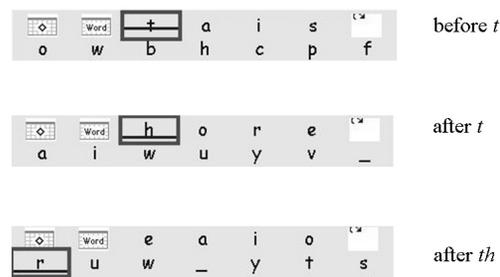
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52 7053
54 71 Figure 1: CVK Onscreen Keyboard55
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74 Text input using the CVK can be achieved using pointing devices or, for patients with
75 too little motor capacity to use a pointing device, via automatic scanning. When a pointing
76 device is used, the user positions the cursor using a pointing device over the desired virtual
77 key and then validates the choice. This type of mode fits, for instance, the needs of people
78 with functional tetraplegia who use a head pointing device. For people who can only control
79 their physical environment by means of a single switch, an automatic process enables the
80 cursor to successively scan all the relevant positions of the screen. When the intended key is
81 reached by the cursor, the user validates that key using a switch. This form of text input is,
82 however, very slow. Two types of scanning mode were used in this study: row-column and
83 linear. The row-column mode significantly reduces the number of cursor shifts needed to
84 reach the intended key but requires two keystrokes (line and column) to select each item, thus
85 increasing the physical effort of the user. Linear scanning requires only a single keystroke
86 since all the keys are systematically scanned successively. When used with a static AZERTY
87 keyboard, text input speed is therefore dramatically reduced if the intended key is situated at
88 the end of the keyboard.

89 Two types of keyboard exist within the CVK: a standard onscreen static AZERTY
90 keyboard and a dynamic onscreen keyboard. The dynamic mode is based on the Sibylle AAC
91 system (Wandmacher [25]) and consists of an automatic rearrangement of the characters on
92 the keyboard after each selection such that the characters that are most likely to be typed next
93 are displayed next to the character which has just been typed, taking into account the
94 previously selected letters. This rearrangement is achieved by the stochastic letter prediction
95 module of Sibylle, which was trained on a large corpus of around 100 millions words. Figure
96 n°2 illustrates this dynamic modification of the keyboard display (English version of Sibylle)
97 when the user tries to write the word *three*. At first, the letters are set in the following order :

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3 98 *t, a, i, s, o*. The letter *t* is the most frequent letter that begins a word in the trained corpus.
4
5 99 When, the user selects the letter *t*, the keyboard is automatically rearranged in the following
6
7 100 new order : *h, o, r, e, a ...* Here, the letter *h* is proposed first since it is the most likely to
8
9 101 occur after the letter *t*. In other words, the conditional probability $P(w_i | w_{i-1} = t)$ is maximum
10
11 102 with $w_i = h$. The letter prediction module of the CVK is based on a 5-gram language model
12
13 103 $P(w_i | w_{i-1}, | w_{i-2}, | w_{i-3}, | w_{i-4})$, which means that the system considers the last four selected
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15 104 letters for the reorganisation of the keyboard layout.
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35 106 Figure 2 : Reorganization of the dynamic letter sub-keypad (English version of
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37 107 Sibylle)
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41 109 Theoretically, this dynamic keyboard should speed up the access time to the intended
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43 110 key and thus increase text input speed. As noted in introduction, text input speed can also be
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45 111 increased by means of word prediction, in order to reduce the number of keystrokes required.
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50 113 The CVK (figure n°1) includes a word prediction module which is based on SibySem, a
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52 114 context-sensitive prediction module which has been shown to reach state-of-the-art
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54 115 performances in French, English and German (Wandmacher [26]). This module is not based
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56 116 on a simple dictionary like standard commercial systems. It is based on a language model
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3 117 which considers the last two words already typed as well as the semantic context of the
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5 118 message. New words are learned dynamically by the system as input continues. Moreover, the
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7 119 system gradually learns the language style of the user. This prediction system is innovative in
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9 120 that word prediction is based on the lexical meaning of the sentence. This characteristic
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11 121 allows the prediction to adjust dynamically to the current topic of interest. Experiments with
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13 122 participants have shown that the word prediction systems can achieve about 60% Keystroke
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15 123 Savings (Wandmacher [26]) when five predicted words are displayed at a time.

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18 124 The SibySem module provides a list of six - seven predicted words displayed on the
19
20 125 screen. The prediction list is displayed horizontally at the top of the virtual keyboard in figure
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22 126 1 (*bien, beaucoup, bon...*), and vertically on the left of the keyboard in figure 3.



36
37 *Figure 3: CVK dynamic on-screen keyboard with word prediction list on the left*

38 39 40 41 128 **Text input modes**

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44 129 In this study, four different modes of the CVK software were compared:

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- 47 • static on-screen keyboard
 - 48 • static on-screen keyboard with word prediction
 - 49 131
 - 50 132 • dynamic on-screen keyboard
 - 51 133 • dynamic on-screen keyboard with word prediction.

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55 134 The static mode consisted of a virtual keyboard with the standard AZERTY layout. The
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57 135 static+word prediction mode consisted of this virtual AZERTY keyboard coupled with the

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3 136 Sybille word prediction system. The word prediction display was located at the top of the
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5 137 onscreen keyboard and presented seven words (Figure n°1). The scanning system integrated
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7 138 within the static keyboard was row-column. The dynamic mode consisted of a virtual
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9 139 keyboard whose layout changed after each character input to display the characters most
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11 140 likely to be selected next. In the dynamic+word prediction mode, Sybille was used in addition
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13 141 to the dynamic keyboard. The word prediction display was located to the left of the dynamic
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15 142 keyboard and presented five words (Figure n°3). The scanning system integrated within the
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17 143 dynamic keyboard was linear.
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23 145 **Study design**

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25 146 This was a pilot study for which ethical approval was not necessary according to French
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27 147 law, since it was an evaluation of usual practice.
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29 148 The study was carried out over 2 months. The CVK was downloaded on each
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31 149 participant's computer. The participants used their usual interfaces (e.g. trackball, switch,
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33 150 mouse, joystick, or head-controlled device). Specific software was coupled with the CVK to
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35 151 record quantitative data such as software use in hours per day and number of characters typed.
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38 152 An experienced occupational therapist spent 1 hour with each participant to explain the
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40 153 function of the four study modes. The rationale behind word prediction and dynamic
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42 154 keyboard was explained but subjects were not given specific guidelines or strategies regarding
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44 155 their use. During the first month, the participants tested the four CVK modes.
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47 156 The modes opened randomly with each CVK session. However, the participants could
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49 157 close the currently opened mode, thus obtaining access to another mode, and could therefore
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51 158 completely avoid the use of one or more modes should they wish to. This choice was made
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53 159 was because we felt it was unfair to limit the participants to use of a mode which he/she may
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160 find restrictive. We were conscious that times of use during the study were therefore likely
 161 not to be equal.

162 At the end of the first month, the occupational therapist (SP) returned to the
 163 participant's home to carry out the assessment. The participant then chose the mode he or she
 164 preferred and used it for the next month.

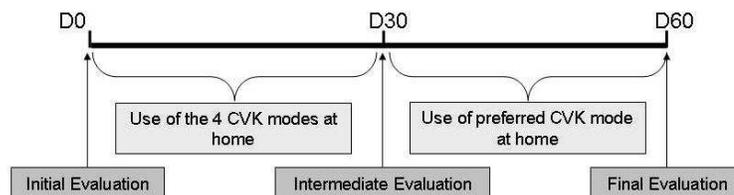
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167 **Assessment**

168 Three evaluation sessions were carried out: one at baseline (D0), the second at the end
 169 of the first month (D30), and the third at the end of the second month (D60) (Figure n°4).

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171

172 *Figure 4 : The three evaluations*

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174 For each of the 3 assessments (D0, D30, D60), all the modes of CVK were evaluated in
 175 a random order. During the evaluation sessions, input speed during a copying task was
 176 evaluated using a 400-word text that the participant was asked to type in less than 10 minutes.
 177 Participants were instructed to use the word prediction and the dynamic keyboard as desired,
 178 i.e. no instructions regarding strategies of use were given. Four texts of similar complexity
 were used, drawn from national newspapers with an average word length of 5.3 characters \pm

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3 179 0.3 (SD), one for each of the four study modes. In this way, the same text was not associated
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5 180 with the same CVK mode .
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8 9 182 **Outcome measures**

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14 184 During the three evaluations, objective data such as text input speed (number of
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16 185 characters per minute) were collected, including punctuation marks and spaces. Selection
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18 186 errors, backspaces and correction times were not taken into account. At the D30 and D60
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20 187 evaluations, satisfaction was evaluated using a 0-10 visual analogue scale (VAS). On D30, the
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22 188 participants were asked to classify the four modes in order of their preference.
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25 189 In addition to these evaluation sessions, the CVK automatically recorded time of use of
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27 190 the device by the participants in their home environments outside of the evaluation sessions.
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30 191 The recording began as soon as the cursor of the mouse moved in the zone of the onscreen
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32 192 keyboard and stopped when the cursor moved out with the keyboard or was static over the
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34 193 onscreen keyboard. For participants who used a scanning system, the recording was stopped
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36 194 at the end of three runs without a selection.
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39 40 196 **Data analysis**

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42 197 To compare the effect of the four modes on text input speed, repeated-measures
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44 198 ANOVAs were carried out. Keyboard (static or dynamic), word prediction (yes or no) and
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46 199 evaluation (D0, D30, or D60) were the factors included evaluated.
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3 201 **Results**
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7 203 **Participants**
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11 205 **Table 1:** Characteristics of participants (P: participants using a pointing device; S, participant
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14 206 using linear scanning)
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Participants	Age (years)	Sex	Diagnosis	Device
P1	22	M	Myopathy	Pointing
P2	41	M	Locked-in syndrome	Pointing
P3	35	F	Locked-in syndrome	Pointing
P4	26	F	Myopathy	Pointing
P5	33	M	Myopathy	Pointing
P6	38	M	Locked-in syndrome	Pointing
P7	32	M	Myopathy	Pointing
P8	44	M	Tetraplegia	Pointing
P9	49	M	Tetraplegia	Pointing
S1	53	M	Locked-in syndrome	Scanning

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10 participants, 8 males and 2 females, with a mean age of 37 ± 10 (SD) years were included. Among them, 4 had locked-in syndrome, 4 had myopathies, and 2 had cervical spinal cord injuries.

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Of the 10 participants, 5 also used their home computer for work purposes. 9 participants used a pointing device to access the computer and 1 participant used a scanning system (row-column pattern). Of the 9 participants who used pointing devices, 4 used a head-pointing device, 4 a specific type of pointer operated by the upper limb (e.g. joystick or trackball), and 1 an eye-pointer. Mean duration of use of the pointing device was 53 ± 37 (SD) months. The habitually used on-screen keyboard was a Windows on-screen keyboard for 5

217 participants, a keyboard available by free download for 3 participants, and a commercially
 218 available keyboard for 2 participants (all were static AZERTY on-screen keyboards). Mean
 219 duration of on-screen keyboard use was 67 ± 67 (SD) months. All of the participants had direct
 220 prior experience with word prediction software but not with dynamic keyboards.

221

222 Usage time of each mode

223 Table 2 shows the usage time of each mode by each participant. Mean usage time over
 224 the 2-month period was 100 ± 105 (SD) hours. At the end of the first month (D30), 3
 225 participants chose the static mode and 6 chose the static +word prediction mode. The
 226 remaining participant was the participant who used linear scanning, and he chose the dynamic
 227 mode. No participants chose the dynamic+word prediction mode.

228 Several participants did not use all four modes during the first month. One participant
 229 intensively used the static and static +word prediction modes (Table 2).

230

231 **Table 2:** Usage time in hours (and as a percentage of overall time of use of the CVK) of each
 232 mode over the 2-month study period for each participant (P: participants using a pointing
 233 device ; S: participant using linear scanning ; St: Static cvk mode ; StW: Static+Word CVK
 234 mode ; D: Dynamic CVK mode ; DW: Dynamic+Word CVK mode)

Participants	First Month				Second Month
	St	StW	D	DW	
P1	0.3 (5.3%)	3.8 (66.7%)	0.4 (7%)	1.2 (21%)	2 (StW)
P2	3.4 (11%)	23 (74.4%)	3.8 (12.3%)	0.7 (2.3%)	21.5 (StW)
P3	15.2 (28%)	22.1 (40.8%)	6.4 (11.8%)	10.5 (19.4%)	20.5 (StW)
P4	38.5 (78.7%)	10 (20.5%)	0.1 (0.2%)	0.3 (0.6%)	29.5 (StW)
P5	12.3 (56.9%)	0.6 (2.8%)	0.1 (0.5%)	8.6 (39.8%)	0.7 (StW)

P6	101.2 (40.8%)	129.3 (52%)	12.8 (5.2%)	5.1 (2%)	122 (St)
P7	41.2 (74.2%)	0.1 (0.2%)	1.9 (3.4%)	12.3 (22.2%)	44.4 (St)
P8	0.3 (0.4%)	24.3 (29.4%)	7.8 (9.5%)	50 (60.7%)	3 (StW)
P9	11.7 (19.4%)	48.6 (80.5%)	0 (0%)	0.1 (0.1%)	20.1 (St)
S1	0.2 (1.2%)	1.7 (10%)	15 (88.2%)	0.1 (0.6%)	8.5 (D)

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236 **Text input speed**

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238 **Table 3:** Mean (SD) text input speed (characters/minute) for each evaluation.

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CVK Modes	D0	D30	D60
	Mean (SD)	Mean (SD)	Mean (SD)
Static	23.4 (12.9)	22.6 (12)	12.7 (2.2)
Static +Word	23 (12.3)	21.5 (12)	24.3 (11.3)
Dynamic	11.9 (4.9)	11.6 (6.5)	5.5*
Dynamic+Word	11.5 (6.9)	12.9 (7.6)	N/A

240 *Only S1

241

242 The optimal use of an unfamiliar on-screen keyboard may require a learning process. We
 243 performed longitudinal measurements to evaluate the effects of usage over time (Table 3).

244 There was no significant change in text input speed across evaluation sessions ($p=0.97$)

245 (Table 4). Neither were there any significant interactions between mode and evaluation

246 session. Consequently, the results of the three evaluations were averaged.

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249 **Table 4 : ANOVA**

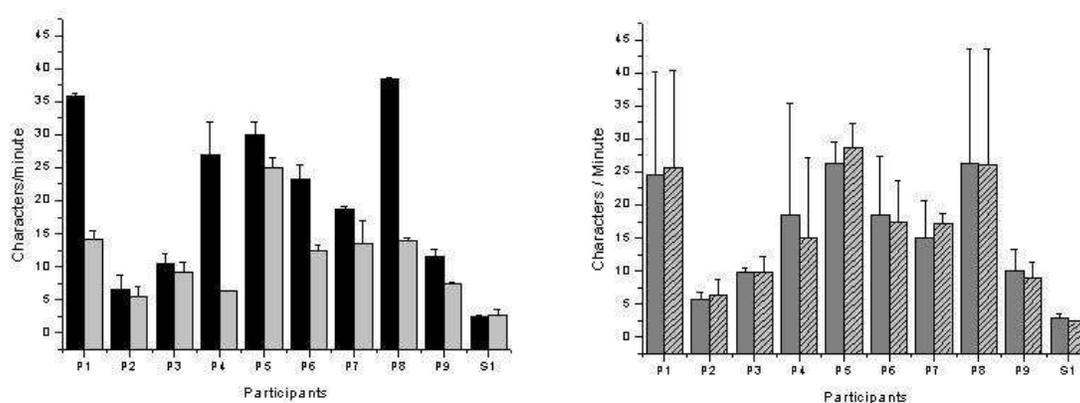
Effect	p-value
Time (D0 vs D30 vs D60)	0.97
Keyboard type (Static vs Dynamic)	0.01
Word prediction (With vs Without)	0.82
Keyboard type * Word prediction	0.4
Time * Word prediction	0.55
Keyboard type * Time	0.34
Time * Keyboard type * Word prediction	0.19

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252 **Effect of mode on text input speed**

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255 *Figure 5 : Text input speed (characters/minute) (mean (SD) of the 3 evaluation sessions for each patient) (P: participants using a pointing device; S, participant using linear scanning)  static;  dynamic;  without word prediction;  with word prediction*

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256 Use of the dynamic keyboard decreased text input speed by a mean of $37\% \pm 27$ (SD)
 257 compared with use of the static keyboard. This reduction was statistically significant ($p=0.01$)
 258 (Table 3). Use of word prediction had no effect on text input speed ($p=8.2$). There were no
 259 significant interactions between modes.

260 We identified no characteristics (e.g. age, sex, type of pointing device, diagnosis, usage
 261 time, or time since acquisition of the pointing device) that appeared to be related to whether
 262 the dynamic keyboard or word prediction tool increased or decreased text input speed.

264 Participant satisfaction

266 **Table 5:** Visual analogue scale satisfaction scores (out of 10) (P: participants using a pointing
 267 device; S, participant using linear scanning)

268 *denotes the mode chosen by each participant for the second month of the study

Subjects	CVK Modes			
	Static	Static + Word	Dynamic	Dynamic + Word
P1	7	6*	2	3
P2	5	6*	3	5
P3	2	5*	2	0
P4	5	4*	1	0
P5	6	7*	5	4
P6	7	7*	0	0
P7	9*	8	4	4
P8	7	6*	0	0
P9	7*	6	3	3
S1	5	6	7*	7

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3 271 Table 5 shows the level of satisfaction of each participant on the VAS. All 9
4
5 272 participants who used pointing devices reported greater satisfaction with the static keyboard
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7 273 than with the dynamic keyboard. However, the participant who used linear scanning was
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9 274 more satisfied with the dynamic keyboard.

11 275 At the end of the study, 9 of the 10 participants reported that they preferred to keep their
12
13 276 own on-screen keyboard. A single participant who used a pointing device, wanted to keep the
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15 277 CVK (in the static +word prediction mode) instead of the Windows XP keyboard he used
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17 278 previously.

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22 280 **Discussion**

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27 282 The primary aim of this study was to carry out a preliminary evaluation of the effect of
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29 283 a dynamic on-screen keyboard and the addition of a word prediction tool to a static and
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31 284 dynamic on-screen keyboard on text input speed. We hypothesized that both word prediction
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33 285 and the dynamic keyboard would increase text input speed and thus the combination of both
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35 286 systems would further increase text input speed, however the results showed that our
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37 287 hypotheses were false. The main findings were that use of the dynamic keyboard decreased
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39 288 text input speed compared with the static keyboard and the addition of word prediction neither
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41 289 increased nor decreased text input speed. Most participants preferred to return to their habitual
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43 290 keyboards at the end of the study.

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51 293 **Dynamic versus standard keyboard**

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53 294 Dynamic keyboards have existed for several years, and are particularly used by people
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55 295 who use scanning systems (Heckathorne [17]) (Gibler [27]) to increase text input speed and

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3 296 communication rate (Heckathorne [17]) (Baletsa [28]), although they were also designed for
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5 297 people who use pointing devices (Wandmacher [26]) (Merlin [19]) (Ward [16]). In 2009-
6
7 298 2010, our team developed a dynamic keyboard which was intended for use by users of both
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9 299 scanning systems and pointing devices (Wandmacher [26]).

10
11 The results of our study, although preliminary, suggest that dynamic keyboards may be
12
13 301 ill-suited for participants who use pointing devices. Text input speed was decreased by the
14
15 302 dynamic keyboard compared with the static keyboard and only one participant (the participant
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17 303 who scanned) chose to continue using the dynamic keyboard during the second month of the
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19 304 trial, suggesting a lack of subjective benefit in most cases. However, our results contrast with
20
21 305 those of Merlin and Reynal (2010) who showed that their dynamic keyboard improved text
22
23 306 input speed by 20% compared with a static QWERTY keyboard in 6 disabled participants
24
25 307 who used pointing systems (Merlin [19]). This difference may be explained by the fact that
26
27 308 the type of prediction system used was different. In their system, the characters which had a
28
29 309 low probably of being selected were replaced by those with a high probability, thus creating a
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31 310 repetition of these characters across the keyboard and increasing the ease with which they
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33 311 could be selected (Merlin [19]). In our keyboard, only the position of the character is altered
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35 312 according to its selection probability, requiring the subject to search for the desired character.
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37 313 Since the disposition of the characters cannot be learned, this may increase the cognitive load
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39 314 of the task (Leshner [29]).

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45 315 Although there are very few studies on the effects of the design of dynamic keyboards
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47 316 on text input speed in disabled subjects, it is likely that the design is important. For example,
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49 317 the layout of static on-screen keyboards has been shown to affect text input speed in healthy
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51 318 and disabled subjects (Vigouroux [30]), (Raynal [31]), (Vigouroux [32]). Several studies have
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53 319 also shown that the keyboard layout also affects text input speed in healthy subjects using
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55 320 scanning systems (Leshner [29]).

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3 321 Despite the fact that the dynamic keyboard had no effect on his text input speed, the
4
5 322 single participant who used linear scanning in our study chose to keep this device during the
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7 323 second study month. This suggests that there was a subjective advantage of this keyboard for
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9 324 this participant. The subjective benefits of dynamic keyboards in have previously been
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11 325 described in participants with motor disability who use scanning systems (Heckarhone [17]).
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13 326 This advantage of the dynamic keyboard when used with scanning systems requires
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15 327 confirmation in larger numbers of participants who use scanning systems, such as those with
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17 328 amyotrophic lateral sclerosis, locked-in syndrome, and advanced multiple sclerosis.
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22 23 330 **Effect of word prediction**

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25 331 The goal of word prediction is to increase text input speed by eliminating the need to
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27 332 select each letter in the word. Although it has been demonstrated that word prediction reduces
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29 333 the number of keystrokes, at least in healthy subjects (by 10-39.6% when coupled with a
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31 334 dynamic keyboard and by 7.9% when coupled with a static keyboard) (Leshner [29]), the
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33 335 effects on text input speed are disparate. The results of our study showed that the addition of
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35 336 word prediction had no effect on text input speed. This result is similar to some results in the
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37 337 literature and contrasts with others. Closer examination of the literature suggests that the
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39 338 different effects of word prediction found may be related to the user population and/or the
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41 339 type of system it is coupled with. Studies in healthy subjects have found improvements of
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43 340 approximately 3 words per minute in healthy subjects using word prediction with on-screen
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45 341 keyboards but not with standard keyboards (Anson [22]), (Anson [33]). Word prediction did
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47 342 not, however, appear to be effective in healthy subjects using a scanning system (Koester
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49 343 [21]). Koester and Levine (Koester [23]) found that word prediction slightly improved text
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51 344 input speed in healthy subjects using a mouth stick on a standard computer keyboard while it
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53 345 significantly decreased text input speed (by a mean of 41%) in high-level tetraplegic subjects.
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3 346 Other studies in disabled participants have also found negative results for the use of word
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5 347 prediction. A previous study by our group (Laffont [34]) which evaluated the addition of
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7 348 word prediction in adults with cerebral palsy who used voice synthesizers found no
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9 349 significant improvement for 4 out of 10 participants. In a series of studies involving
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11 350 individuals with spinal cord injury and persons with normal abilities, Koester (Koester [21])
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13 351 (Koester [23]) found that the word prediction system reduced the number of key selections
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15 352 necessary, however, each selection took significantly longer to make, leading them to suggest
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17 353 that the cognitive costs of using a word prediction system overshadowed any potential benefit
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19 354 associated with the method, particularly for the patient group.
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23 355 The effect of word prediction might be influenced by several parameters. Different search
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25 356 strategies can influence input text speed, such as the number of letters the subject types before
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27 357 searching the list (Koester [35]). This was not evaluated in the present study since we gave no
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29 358 indications to the disabled participants in order to assess their spontaneous use. Further studies
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31 359 regarding this factor would provide useful information to therapists for training disabled
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33 360 participants.
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36 361 The number of predicted words provided is also likely to be an important factor because
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38 362 of the time required to scan the list. The Sybille system displays six - seven predicted words at
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40 363 a time. There is a trade off between the time gained as a result of keystroke savings when
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42 364 using word prediction and the time lost in searching a list of predicted words (Koester [35]).
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44 365 Following a series of studies Koester et al. (Koester [21]) (Koester [23]) suggest that each
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46 366 additional word in the list increases search time by 150ms. In a simulation study, Swiffin
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48 367 (1989) found that beyond 6 words, the list search time outweighed the keystroke savings
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50 368 (Swiffin [36]). However, at present, there are too little data in disabled people to determine
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52 369 the optimal number of words which should be displayed for such populations.
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3 370 Another parameter that may influence the effect of word prediction is the position of the
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5 371 predicted-word list on the screen. We used two positions (above the static keyboard and left
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7 372 of the dynamic keyboard) and although they are typically used, we do not know what their
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9 373 effect on text entry speed might be. Although there are some indications in the literature that
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11 374 the location of the prediction list might affect the accuracy of text entry and the ease of use of
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13 375 word prediction (Tam [37]), (Tam [38]), the optimal position remains to be determined.

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15 376 It is interesting to note that although word prediction did not improve text input speed,
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17 377 7 of the 10 participants chose to continue using the word prediction mode during the second
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19 378 study month, suggesting that they perceived a subjective benefit. They perhaps wanted to
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21 379 have the possibility to use it if they wished, indeed some expressed this: “I can use it when I
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23 380 need to”. Some participants also expressed difficulties in looking for words in the list whilst
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25 381 paying attention to the keyboard, the text to be copied, the text they were writing etc. which
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27 382 reflects the notion of a high cognitive load.
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33 34 384 **Patient satisfaction**

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36 385 At the end of the study, 9 of the 10 participants reported that they preferred to keep their
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38 386 own on-screen keyboard. We suggest that the reason for this is that the dynamic keyboard
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40 387 perturbed most of the users since they could not learn the position of the letters. With regard
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42 388 to the static keyboard evaluated, the patients already used static AZERTY keyboards and
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44 389 were more familiar with their own. There may also be an element of resistance to change to a
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46 390 new device, termed path dependence. For example, Dvorak showed that the layout of the
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48 391 qwerty keyboard was taken from the design of early typewriters and has not changed despite
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50 392 arguments that other layouts may be more efficient or ergonomic (Dvorak [9])
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3 395 **Limitations**

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5 396 This study has several limitations. The time spent by each participant on each usage
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7 397 mode was not equal which may have influenced the results. It is possible that with more
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9 398 practice on certain modes, there might have been more improvements. However, the fact that
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11 399 subjects chose not to use certain modes suggests that they did not find them helpful.

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14 400 The word prediction dictionary (Higginbotham [39]) and texts used can also influence
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16 401 text input speed, however, we randomized the texts and Sybille contains a large dictionary
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18 402 and we thus hope that any effect was limited.

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23 404 **Conclusion**

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25 405 In this preliminary study, the dynamic keyboard and the addition of a word prediction
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27 406 tool failed to improve text input speed compared to a static on-screen keyboard without word
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29 407 prediction in adults with functional tetraplegia who used pointing devices and scanning
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31 408 system.

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34 409 These results highlight the importance of testing assistive systems in the participants'
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36 410 everyday setting to ensure that the product under development meets the needs of the future
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38 411 users.

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41 412 Our study raises questions regarding many points, such as the best ergonomic design of
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43 413 a dynamic keyboard and the optimal number and position of words that should be predicted.
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45 414 Future studies should aim to address these questions in larger numbers of participants who use
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47 415 scanning systems.

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Declaration of Interest statement

None of the authors has any declaration of interest to report regarding this study.

For Peer Review

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3 589 **Figure 1:** The CVK on-screen keyboard
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8 591 **Figure 2:** Reorganization of the dynamic letter sub-keypad during input of the first two letters
9 of the word 'three'.
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16 594 **Figure 3:** CVK dynamic on-screen keyboard with word prediction and letter prediction
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21 596 **Figure 4:** The three evaluations
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26 598 **Figure 5:** Text input speed (characters/minute) during a copying task (P: participants using a
27 pointing device; S, participant using linear scanning)
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31 600  static;  dynamic;  without word prediction;  with word
32 prediction
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39 603 **Figure 6:** text input speed (characters/minute) during spontaneous text production (P:
40 participants using a pointing device; S, participant using linear scanning). All modes were not
41 604 evaluated by all participants, as some participants switched off specific modes during home
42 605 use.
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48 607  static;  dynamic;  without word prediction;  with word
49 prediction
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3 610 **Figure 7:** Effect of the practice period on text input speed (characters per minute) during the
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5 611 copying task (P: participants using a pointing device; S : participant using linear scanning).
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7 612 During Evaluation 3, some participants did not use all four modes.
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10 613  Evaluation 1;  Evaluation 2;  Evaluation 3
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15 615 **Table 1:** Characteristics of participants (P: participants using a pointing device; S, participant
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17 616 using linear scanning)
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21 618 **Table 2:** Usage time (hours) of each mode over the 2-month study period in each participant
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23 619 (P: participants using a pointing device; S, participant using linear scanning)
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29 621 **Table 3:** Mean text input speed (characters/minute)
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34 623 **Table 4:** Visual analogue scale satisfaction scores (P: participants using a pointing device; S,
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36 624 participant using linear scanning)
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39 625 *denotes the mode chosen by the participants for the second month of the study
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For Peer Review

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People with disabilities can have difficulty using a computer and may type very slowly. We tested two systems designed to improve typing speed, based on virtual keyboards in 10 severely disabled people. Word prediction improved typing speed for 1 in 2 people. A dynamic keyboard (which predicts the next letter) may be useful for people who cannot use a pointing device but not for those who can. Further studies are needed to improve the ergonomic design of the word prediction system and to test the dynamic keyboard on more people.

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