EVALUATION OF AAC FOR TEXT INPUT BY TWO GROUPS OF SUBJECTS:

Able-bodied Subjects and Disabled Motor Subjects

Nadine Vigouroux, Frédéric Vella, Philippe Truillet, Mathieu Raynal

DIAMANT Team
IRIT (Institut de Recherche en Informatique de Toulouse)
Paul Sabatier University
118, Route de Narbonne, 31062 Toulouse Cedex, France
{vigourou, vella, truillet, raynal}@irit.fr

Abstract. Written communication and keyboard interaction is important for the information society technology. Consistent efforts have already been made using assistive aids for the motor-impaired.

There has also been an important development in the field of cellular phones and personal digital assistants used in the context of mobility. Both these keyboards can create problems for written tasks. However, there exists several models capable of estimating the user's performance while inputting texts.

The aim of this paper is firstly, to present the three most current models used to evaluate the predictive behaviour of the user; Fitts' law, GOMS and Hick-Hyman models. Secondly, we will describe an experiment that compares the AZERTY virtual keyboard to a virtual telephone keyboard, both with and without language prediction system.
The experiment was carried out on two groups: able-bodied subjects and disabled subjects.

Finally, the theoretical and practical results were compared and discussed. The results of this experiment will hopefully improve the Fitts' law and GOMS models.

1. INTRODUCTION

Written communication is a cognitive activity which is increasingly used to exchange digital information. It mainly concerns the inputting of texts and the access to Service Providers via Internet. Communication by e-mails and SMS (Short Message Services) has increased due to the increasing use of cellular phones and handheld devices.

Since the 1980's, considerable research has been developed vis-a-vis Augmentative Alternative Communication (AAC) [Johansen 02] on text entry tasks thanks to instrumented handwriting and soft keyboards[1]. This research has been developed in several different ways:

1. Natural Language Processing with prediction process [Hunnicutt 01], [Maurel 01], [Boissière 02], [Matiasek 02], [Zagler 03], etc.,
2. Time and movement studies [MacKenzie 99], [MacKenzie 01], [Zhai 02],
3. Human-machine interaction process (scanning principle [Card 80], layout optimisation [MacKenzie 99], novice users' initial performance [Smith 01], visual clues [Magnien 03]).

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[1] We define by « soft keyboard » a numerical representation of a physical keyboard (AZERTY, QWERTY, etc.). This representation is comparable to an interactive system having at its disposal a visual interface containing interaction buttons. They can correspond to one or several alphabets codes (phonemes, latin characters, etc.) or function keys. These function keys could be displayed in any input window by making a direct interaction on buttons thanks to any pointing device.

Considering the amount of research already done, it may seem unnecessary to continue studies in the AAC field and text inputting. However, we believe that this is not the case. Because of the development of mobile computing and the arrival of miniaturized and multiple-key keyboards known as ambiguous keyboards (i.e. telephone keyboards [Masakatsu 96], [Kühn 01]), further research on input assistant optimisation is necessary, especially in the field of understanding human performance when using virtual keyboards both by able-bodied and disabled subjects.

The text input task for users suffering from Spinal Muscular Atrophy[2] was carried out using a virtual keyboard with a pointing device. This activity created certain problems: the disabled subjects needed a longer period of time to perform this action; they also had difficulty pointing and moving the device (trackball, mouse) with precision, thus increasing their fatigue.

These subjects experienced fatigue while carrying out long continuous actions. Consequently, they needed considerable time to recover their force. The text input was one of the most difficult and tiring actions to carry out. When the subjects inputted texts they used an AZERTY virtual keyboard with a pointing device and had to move the pointer a certain distance to select each letter.

However some virtual keyboards have a spatial configuration of keys that are not adapted to disabled people because the distance is too far between the keys. This subsequently slows down the text input and causes fatigue. This explains why we were particularly interested in studying the various spatial configurations of virtual keyboard keys.

As a result, our long-term goal is both to improve the speed rate of inputting task and to reduce fatigue. Our primary objective is to develop AAC which:

1. Incorporates language technology,
2. Considers the results of users' performance using neurophysiologic laws,
3. Allows multi-modal input (mouse, eye tracking and speech recognition).

The objective of this paper is to discuss the limits of human performance models elaborated for able-bodied subjects as a predictive model for disabled subjects. We will first describe the three main human performance models that already exist, secondly present the experiment that was carried out and finally discuss the results of the experiment with regard to the predictive results produced by the models.

2. USERS'MOTOR PERFORMANCE FOR TEXT INPUT

Until now research on human computer interaction has been focused on predicting and modelling the time needed for subjects to execute tasks. The time dimension is still an open question. Which input device, keyboard layout, or scanning technique will allow the fastest and most accurate text input via the virtual keyboard?

In this second part, we will report on several time prediction models: Fitts' law, GOMS model and Hick-Hyman law. We were firstly interested in the comparison of time prediction and secondly in the understanding of disabled human performance when executing a text inputting task using a soft keyboard.

2.1. Fitts' law [Fitts 54]

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[2] http://www.mda.org.au/specific/mdasma.html

Fitts' law is one of the oldest models of user performance (Formula 1). The prediction is based on the distance between the keys ($A_{i,j}$) and the size of the target key (W_j):

$$MT=a+b.ID \qquad (1)$$

$$ID=\log_2\left(\frac{A_{ij}}{W_j}\right) \qquad (2)$$

$$IP=\frac{ID}{MT} \qquad (3)$$

- ID represents the difficulty achieving a movement from key W_i to W_j ; it characterizes the human rate of information processing (Formula 1);
- MT, the time prediction in seconds of this movement, depends on the two parameters *a* and *b* (Formula 1). These parameters are empirically determined, see [Zhai 02];
- IP (Formula 3) indicates the Fitts' law index of performance [Fitts 54]; it depends on the layout, the pointing device on the nature of the task (text input, navigation command, etc.) and on the limb movement distance. IP is a sort of "bandwidth" which is used to compare virtual keyboards, taking into account the criteria that determine the difficulty of physical movement. This parameter is measured in bps (bits per second). It represents in seconds the ratio of ID (in bits) to MT.

There still remains questions about Fitts' law, especially relating to the ID parameter. Research already done on index difficulty for "easy tasks" (ID < 3 bits) has suggested possible modifications of the formula proposed by Welford [Welford 68] (Formula 4).

$$MT=a+b.\log_2\left(\frac{A_{ij}}{W_j}+0{,}5\right) \qquad (4)$$

Another improvement of Fitts' law is based on its deviation compared to Shannon's information theory. This deviation specifically implied that the formulation did not correspond to field observations, and could possibly give a negative rating for the index of task difficulty. Consequently the following modified equation for the difficulty index was suggested [MacKenzie 92].

$$MT=a+b.\log_2\left(\frac{A_{ij}}{W_j}+1\right) \qquad (5)$$

More recently Zhai and his colleagues [Zhai 02] have proposed an adaptation of Formula 5 by taking into account the weighted average among all the different pairs of letters. This brings us to Formula 6 for an AZERTY keyboard:

$$MT=\sum_{i=1}^{27}\sum_{j=1}^{27}\frac{P_{ij}}{IP}\left[Log_2\left(\frac{A_{ij}}{W_j}+1\right)\right] \qquad (6)$$

Table 1 summarizes the results of this calculation based on some well known keyboard layouts. This computation is made on the basis of 5 characters per word (a space is considered as a character). Formula 6 allows us to estimate the typing speed in Words per minute (Wpm).

Keyboard Layout	IP=4.9 bps	IP=6 bps	IP=8 bps
QWERTY Sholes & Glidden[3]	28 Wpm	34,3 Wpm	45.7 Wpm
FITALY[4] Textware Inc	36 Wpm	44.1 Wpm	58.8 Wpm
OPTI MacKenzie & Zhang [MacKenzie 99]	38 Wpm	46.5 Wpm	62.0 Wpm
Metropolis Zhai, Hunter & Smith [Zhai 00]	43 Wpm	52.7 Wpm	70.2 Wpm
ATOMIK Zhai, Smith & Hunter [Zhai 01]	41.2 Wpm	50.4 Wpm	67.2 Wpm

Table 1. Performance estimation of expert users with various virtual keyboard layouts according to [Zhai 01].

Some Wpm rates are very high with regard to the experiments [Zhai 02]. Zhai commented on this theoretical input speed (70.2 Wpm) with (IP=8 bps and b = 1/IP). Consequently, a new problem arose: how to define the *a* and *b* parameters?
Following evaluation trials on Metropolis keyboard for valid users, Zhai [Zhai 00] proposed modifications to the values *a* and *b*. These values corresponded more accurately to the reality.

$$MT = 0.083 + 0.127 . ID \qquad (7)$$

With formula 7 the inputted Wpm for any keyboard type seemed coherent with the reality [Zhai 02] for valid users. The question raised was what would be the values of the *a* and *b* parameters when applied to models adapted for motor disabled users? Disabled users were unable to carry out certain movements or selections and this resulted in slower input compared to able-bodied ones. Therefore, it was necessary to conduct further research to determine the values of the *a* and *b* parameters in order to build dynamic functions.

2.2. GOMS method [Card 80]

According to the GOMS model, the text input time corresponds to the sum of the total time of the various activities:

$$T = T_K + T_P + T_H + T_D + T_M + T_R \qquad (8)$$

T: total time necessary to execute a task ; T_K: time to click ;T_P: pointing time; T_H: time to take the input device; T_D: time to move the cursor from one point to another; T_M: time of the user's mental activity and T_R: system answering time (negligible).

2.3. Hick-Hyman law [Hick 52], [Hyman 53]

There also exists the Hick-Hyman law which determines the time necessary to choose a key on a keyboard layout. It is expressed according to Formula 9.

$$RT = a + b \log_2 (n) \qquad (9)$$

n: the number of characters; *a*: the reaction time when the all the items are reduced to one single process; *b*: in seconds per bit; the inverse represents the rate depending on the subject choices.

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[3] http://www.precision-dynamics.com.au/typewriters/sholes.html
[4] www.fitaly.com

In the case of a novice user, the model [Masakatsu 96] set the values *a* and *b* respectively to *0* and *0.2* and these were the values adopted.

$$RT= 0.2 \log_2(n) \qquad (10)$$

2.4. Theoretical results

We calculated the theoretical values for the GOMS model [Card 80] (Formula 8) and the MacKenzie model [MacKenzie 92] (Formula 5). Both of them were applied to the AZERTY keyboard.

As far as the GOMS formula is concerned, we think that other parameters that are not directly linked to movement should also be taken into account.

It is also important to mention the time necessary to perform certain tasks, such as visual perception, manipulation of the pointing device, and the user's mental activity. In fact the research done by of Lesher [Lesher 00] and Bérard [Bérard 04] and as well as our team users' interviews both reported muscular and ocular fatigue. This was caused respectively by the use of the pointing device (the trajectory of the cursor on the keyboard) and by the eye movement used during a double task: 1) scanning prediction lists produced by the AAC and 2) controlling the pointing device.

As a result, in the case of motor disabled people it would be necessary to weigh up the T_i variables by dynamic functions. These variables would model the fatigue during a text inputting task depending on several factors. These factors could be the duration of the task, the average word number on a list of predictions, the area of keyboard layout, the size of the key, etc.

We can also remark that these two models do not produce the same text input speed (2.34 CPS (Character Per Second) for MacKenzie's model (Table 2), versus 0.779 CPS for the model GOMS (Table 3)).
The terms of GOMS equation (Formula 8) are estimations defined by Card studies. This formula still does not integrate the previous remarks concluded from our empirical users' interviews.

We applied the MacKenzie's formula (Formula 5) because it was well adapted to represent the mouse trajectory. We can observe that the size of the keys is considered and consequently the size of the keyboard. One major limitation of this model is that it does not take into account the T_m factor (time of user's mental activity).

	AZERTY
W (cm)	1.00
D (cm)	110363.87
MT (s)	435.62 (7min)
ID	1208.24
IP (bps)	3.39
RT (s)	0.659
Input speed (CPS)	2.34

Table 2: Input time and type speed (Figure 3) according to 230 + 166 × log2(A / W + 1)

	AZERTY
Tk	286.16
Tp	1024.2
Tm	1.379
Td	0
Th	0.4
Tr	0
T	1311.7(21min)
Input speed (CPS)	0.779

Table 3: Theoretical results obtained by GOMS model during text inputting (Figure 3)

3. EXPERIMENTAL PROTOCOL DESIGN

3.1. Aims

The aim of this protocol was to observe the performance of two groups of subjects using virtual keyboards during a controlled text processing task.

The objective of team *DIAMANT* is to compare:

1. The experimental results with the theoretical ones ; the literature of typewriting with virtual keyboard reports that the theoretical models (Fitts, Goms and Hick-Hyman) described above in [MacKenzie 99] were mainly designed for mobile subjects (able-bodied people). An experiment conducted by LoPresti [LoPresti 00] showed that the neurophysiologic models related to the head movements were not adapted to disabled people; does this mean that it has the same effect on hand movements?
2. The difference between human performance of the two test groups depending on which virtual keyboard was used. Our hypothesis was that during the text input task the able-bodied subjects would achieve better results than the disabled subjects, with regard to the CPS parameter.

The aim of this experiment was twofold:

1. To acquire knowledge and to understand human performance when using a virtual keyboard;
2. To obtain data to model functions in the GOMS law and MacKenzie's model according to the subjects tested.

3.2. Experiment

3.2.1. Virtual Keyboards

During the experiment, we used two kinds of virtual soft keyboards: an AZERTY (referred to as C1), and an ambiguous[5] one (phone type). Both types of keyboard were used with and without prediction language. The input devices used were a trackball for disabled subjects and a mouse for the able-bodied.

The AZERTY type keyboard

The AZERTY type keyboard (C1) is made up of 27 keys. The character selection input is executed by clicking on the left-hand button of the mouse (Figure 1a).

The ambiguous keyboard without prediction

The ambiguous keyboard without prediction (C2) is made up of 10 keys. There are three characters assigned to each key (Figure 1b). The character selection is carried out by consecutive left clicks (with a mouse or trackball).

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[5] A keyboard is said to be ambiguous when it contains more than one symbol on a key, like for example the phone type keyboard which displays three characters on each key.

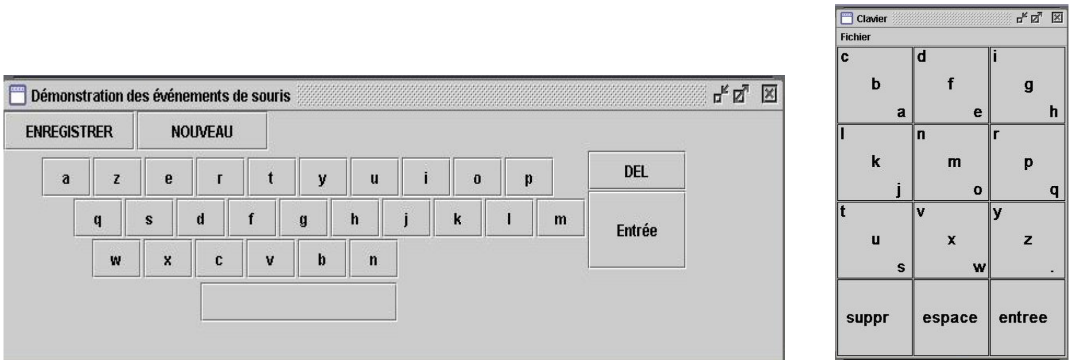

Figure 1: a) AZERTY keyboard b) Phone keyboard (T9)

The ambiguous keyboard with prediction

The ambiguous keyboard with prediction (C3) is based on the same character selection principle as for C2. However the prediction system influences the order (Figure 2) in which the three characters appear on one key and are therefore made accessible.

The order of the display list is determined both by the input context (the *n-1* characters previously inputted) and the probabilities of occurrence obtained by *text corpora* analysis. The N-gram model was used in the same way as the VITIPI system [Boissière 02]. These probabilities were elaborated from a statistical analysis of occurrences of letter sequences in the newspaper “Le Monde” dated 30/05/03 and 31/05/03. This corresponded to 80 000 words.

In this first experimentation phase the *n* value was 2. Thus, the three characters of the key were accessible in a decreasing order according to their probability of occurrence.

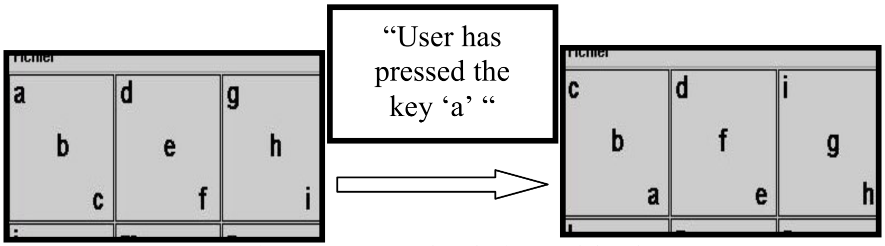

Figure 2: Layout after the input of the character “a”

3.2.2. Hypothesis

In order to study the effect of the key layout during a text input task, we experimented on two types of subjects (subjects suffering from neuro-muscular diseases and able-bodied subjects). We are going to present the following hypotheses of this experiment.

Hypothesis 1: Does the layout of the keyboard keys affect the distance covered in comparison to an input task? The number of keys and the distance that separate them (among others the most distant) being more restricted on a phone type keyboard than on an AZERTY. It can therefore be supposed that, according to Fitts’ law, the distance covered on a “phone” type keyboard would be less than that covered on an AZERTY keyboard.

Hypothesis 2: Theoretically, the prediction system decreases by a third the number of clicks necessary to select a key compared to the number of clicks necessary on the phone keyboard without a prediction system. It can therefore be supposed that the virtual keyboard with prediction would take less time to input information than the one without prediction. Consequently, the underlying hypothesis is that the input time with prediction will be lower than the time obtained with a device without prediction. The validation of hypothesis 1 suggests the following order of input time:

AZERTY keyboard > Phone keyboard without prediction > Phone keyboard with prediction.

3.2.3. Participants profile

These hypotheses were tested on 5 able-bodied subjects and 2 disabled subjects suffering from Spinal Muscular Atrophy. The disabled subjects were used to using the AZERTY soft keyboard (Clavicom[6]) to interact with their workstation. The able-bodied subjects had never used the T9 phone but had often used AZERTY for their work or studies. The ages of the subjects ranged from 24 to 46 years old.

3.2.4. Texts description

The experiment consisted of 9 sessions. The text used (Figure 3) comprised 196 words (1022 characters) with the accents omitted. This text was divided into 6 parts, randomly distributed during the 9 sessions.

> un vieil homme acariatre qui vivait seul depuis toujours et qui allait avoir soixante quatorze ans en decembre ne supportait pas les enfants il habitait une maison entouree d un jardin bien entretenu pour son plaisir et avait a portee de la main dans son entree une canne en bambou dont il menacait les enfants turbulents de la cite hlm voisine
>
> un mardi alors qu il venait de detruire un nid de guepes il s est retrouve coince sur le toit haut de trois metres cinquante car en voulant redescendre tres vite il a fait tomber l echelle en alu qu il avait pose en equilibre instable contre le mur de l appentis comme l homme s est mis a appeler a l aide d une voix forte un gamin courageux qui jouait sagement aux billes dans la rue le long de la cloture a leve la tete a compris la situation et a replace l echelle qui était par terre a cote d un rosier
>
> depuis cette facheuse aventure le dimanche il invite son sauveur blond dans son jardin et pour le remercier lui offre sous les arbres un gouter accompagne de jus de pomme

Figure 3: Text inputted by subjects during the experiment

3.3. Experiment progress

The experiment was conducted over a two week period. There was no appropriation period for the virtual keyboards. The virtual keyboard instructions (strip input and the effect of language prediction) were given to the subjects over a period of ten to twenty minutes.

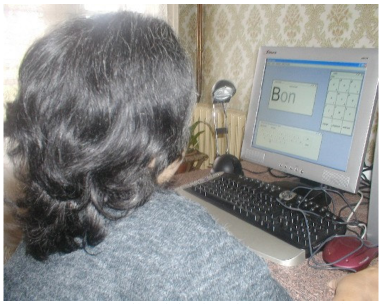

Figure 4: A disabled subject carrying on at her home, an evaluation on a virtual keyboard

Figure 5: Input strip

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[6] http://www.handicap-icom.asso.fr/adaptations/aides_techniques/clavicom.html

Right from the first session, we identified that the subjects needed to learn the keyboard representation, even though the disabled subjects (Figure 4) had already used virtual keyboards (Clavicom, WiVik[7]).

The subjects had to input one of the six parts of the text (Figure 3). This part was proposed to the subject within a strip (Figure 5). The character to be inputted appeared in dark grey, and the two following characters in light grey. The subjects had to input the current character, which involved the updating of the strip.

This process was repeated until the end of the text. An input mistake generated audio feedback. A ten-minute recovery period was attributed to the disabled subjects (this stage was omitted for able-bodied subjects insofar as the physical strain was greater for the disabled subjects during the session).

The subjects had to enter the same text three times, once for each keyboard (Ci, i = 1 to 3). The order of the keyboards was randomly selected.

3.4. Experimental variables

On the e-ASSISTE platform [Vigouroux 04], for each character inputted, the following parameters were recorded:

1. The time parameter in milliseconds (time needed to move the cursor and time to enter the character): This represents the time to type a character;
2. The distance parameter: This is the distance covered by the cursor on the screen from key_i to key_j;
3. The error parameter: 0 if the character is wrong and 1 if the character is correct.

Post-processing was carried out on these parameters in order to compute the CPS, the number of errors and the total distance covered during each session.

4. RESULTS AND DISCUSSION

Firstly, we observed that hypothesis 1 was confirmed for the two categories of subjects (Table 4 & Table 5). In fact, the distances covered during text input were clearly shorter (Figure 6) for ambiguous keyboards than for the C1. This was mainly due to the different number of keys on the two keyboards. The subject covered a greater distance with a C1 keyboard (27 keys) than with the C2 and C3 keyboards (10 keys, more than twice as many for C1 than for C2).

These first results showed that if we reduced the number of keys, we also reduced the distance of the trajectory movement. However, the number of clicks needed to select the character increased. Nevertheless, is the time needed to perform a series of clicks less significant than the time needed to go from one key to another?

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[7] http://www.wivik.com

Sessions	C1	C2	C3
1	643.87	2576.83	2421.01
2	7563.28	2779.87	2654.42
3	5410.32	2105.56	2064.48
4	5337.50	2003.24	1972.04
5	7625.02	2607.17	2612.28
6	5324.83	1994.24	2026.71
7	5658.84	1911.91	1884.02
8	5903.91	2145.55	2172.06
9	4486.82	1702.23	1711.23
Average	**5972.27**	**2202.96**	**2168.69**
Standard deviation	**1056.46**	**365.32**	**327.18**

Table 4: Input distances (able-bodied subjects).

Sessions	C1	C2	C3
1	6586.76	2397.62	2539.98
2	4901.95	2076.70	1985.50
3	2813.17	1373.17	1275.68
4	6181.99	2379.42	2443.93
5	6324.61	2495.16	2275.81
6	5664.12	2082.48	2130.68
7	6060.44	2792.76	2876.79
8	6846.98	2414.51	2406.70
9	5369.82	2082.41	1930.50
Average	**5638.87**	**2232.69**	**2207.29**
Standard deviation	**1219.71**	**398.84**	**455.37**

Table 5: Input distances (disabled subjects).

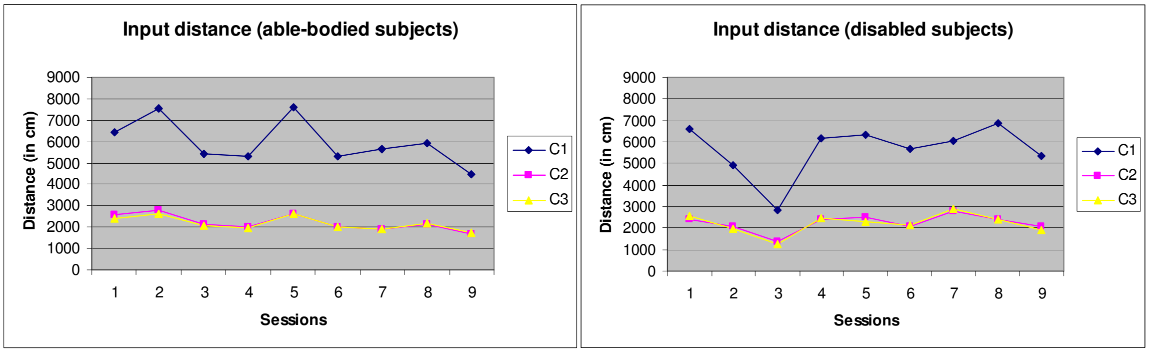

Figure 6: Input distances

Secondly, we noticed that hypothesis 2 was not confirmed. In fact, for the two categories of subjects, the C1 keyboard was faster (Figure 7) compared to the C2 and the C3 keyboards. However C3 outclassed C2. The reason for this rapidity was that the subjects often used the C1 keyboard in their everyday life. Consequently, the spatial configuration of C1 was already familiar to them.

During the sessions, we observed constantly improving performances among the able-bodied subjects. This had already been observed by MacKenzie [MacKenzie 99]. These results were due to a "learning effect" that took place progressively during the nine sessions.

Perhaps, if we had been able to carry out training sessions with able-bodied subjects, we might have seen that the C2 and C3 keyboards were more effective than the C1. In fact, we need to carry out further experimentation.

We noticed however that the disabled subjects made hardly any progress: the standard deviation varied very slightly (Table 7).

One reason for this lack of progress could be that the soft keyboard was not well adapted to their handicap (motor handicap of upper members).

The theoretical results (Table 2 & 3) seemed to be very far from reality (Table 6 & 7). This meant that estimation models were not representative of the subject's behaviour, especially for the disabled subjects.

The variation between theoretical and experimental data was:

1. Respectively +1.18 cps for able-bodied subjects, +1.86 cps for disabled subjects compared to MacKenzie (Table 2) and
2. Respectively +0.299 cps for disabled subjects and –0.381 cps for able-bodied subjects compared to GOMS (Table 3).

Consequently, this comparison raised two discussion points. The need to:

1. Increase the number of subjects to see if the preliminary results were correct;
2. Elaborate prediction models that are closer to the results of the experiment;
3. Add other parameters such as the estimation of fatigue or the effect of the interaction technique.

Sessions	**C1**	**C2**	**C3**
1	0.985	0.546	0.537
2	1.098	0.65	0.626
3	1.176	0.728	0.668
4	1.118	0.765	0.699
5	1.243	0.835	0.77
6	1.243	0.859	0.778
7	1.21	0.862	0.8
8	1.242	0.86	0.794
9	1.208	0.933	0.811
Average	**1.16**	**0.78**	**0.72**
Standard deviation	**0.08**	**0.12**	**0.09**

Table 6 : Input speeds (able-bodied subjects).

Sessions	**C1**	**C2**	**C3**
1	0.552	0.344	0.315
2	0.489	0.36	0.298
3	0.49	0.325	0.29
4	0.457	0.429	0.347
5	0.424	0.363	0.319
6	0.456	0.397	0.321
7	0.461	0.418	0.36
8	0.479	0.438	0.353
9	0.474	0.462	0.406
Average	**0.48**	**0.39**	**0.33**
Standard deviation	**0.04**	**0.05**	**0.04**

Table 7 : Input speeds (disabled subjects).

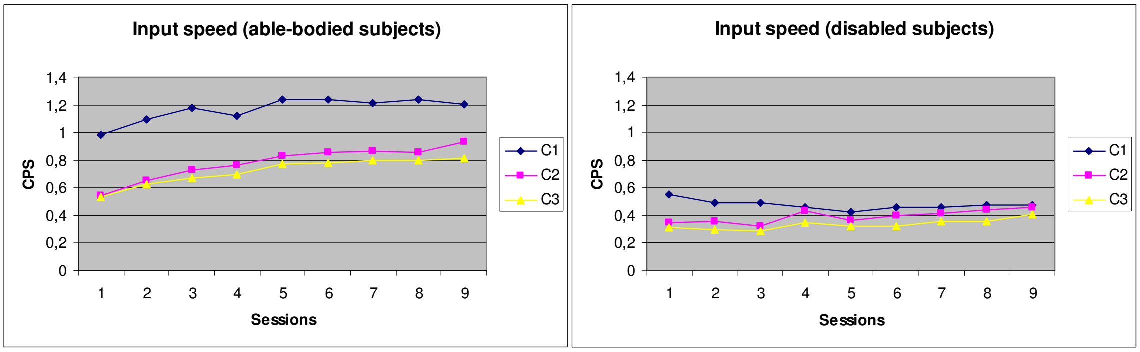

Figure 7: Input speeds in cps (character per second).

Finally, during this experiment we calculated the error rates (Figure 8) and noticed that the disabled subjects (Table 9) made less text input errors than the able-bodied subjects (Table 8). We can also say that the disabled subjects made fewer errors with the C1 keyboard than with the C2 and C3 ones. The able-bodied subjects also made more errors with the C1 keyboard than with the C2 and C3.

The able-bodied participants also paid more attention [MacKenzie 01] to the changing of the configuration of the C3 keyboard and took the time to visualize the position of the characters before selecting them.

The most significant error rate with the C1 and C2 was obtained with the fixed key configuration that was already familiar to the users. Because of this, the users paid less attention to locating the characters on the soft keyboard. This was because the disabled subjects had already used virtual keyboards whereas the able-bodied subjects had never or almost never used them before.

Sessions	C1	C2	C3
1	7	11.6	11
2	12.6	10.4	8.8
3	9.8	5	7.8
4	16.2	5.4	7.2
5	22.2	7.4	12.4
6	19.4	8.4	5.8
7	18	8.8	10.6
8	18	8.6	11.8
9	13.8	6	8.2
Average	**15.22**	**7.95**	**9.28**
Standard deviation	**4.85**	**2.23**	**2.25**

Table 8 : Input error rates (able-bodied subjects).

Sessions	C1	C2	C3
1	11.50	30.00	28.50
2	7.00	10.50	33.00
3	5.00	12.00	12.50
4	15.00	8.00	16.00
5	7.00	9.50	16.50
6	16.50	4.50	13.50
7	13.50	16.50	22.50
8	9.00	10.50	19.50
9	8.00	5.00	8.50
Average	**10.28**	**11.83**	**18.94**
Standard deviation	**4.02**	**7.71**	**7.88**

Table 9 : Input error rates (disabled subjects).

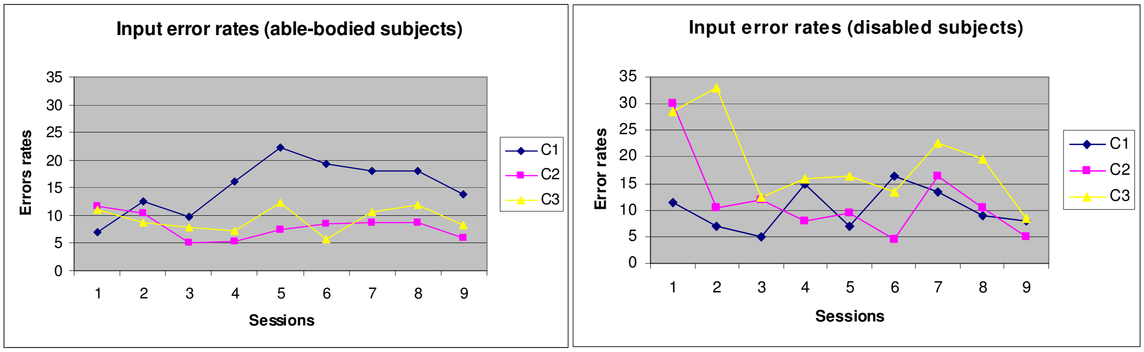

Figure 8: Input error rates.

5. CONCLUSIONS AND FUTURE WORK

As we can see from the results, the C1 keyboard is more powerful compared to the two ambiguous keyboards for both categories of subjects. This is due to the fact that both types of users knew the spatial layout well. However, does this mean that it would be preferable to favour research on non-ambiguous keyboards rather than ambiguous ones?

On the contrary, is it necessary to study other spatial configurations for the ambiguous keyboards? We did not evaluate these two keyboards with enough subjects to give definite answers to all our questions. Consequently, our future research will be to carry out more experiments on these virtual keyboard layouts.

It will also be necessary to conduct other experiments on several keyboard layouts with different spatial configurations. Another important point is to observe the length of the text input activity in terms of fatigue. These new results could then be used to adapt Fitts' model to disabled subjects' needs by suggesting a dynamic function of the parameters *a* and *b*.

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