An evaluation of the "outertype" keyboard

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Rapport nr.: 408

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F.L. van Nes and P. Barbonis

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SUMMARY

1. The Outertype keyboard is a so-called chord keyboard: a syllable is generated in one stroke by depressing several keys simultaneously. Not all letters are represented by separate keys, i.e., several letters have to be formed by depressing two keys simultaneously. On the other hand, some letters, viz. frequently occurring consonants and all vowels, are represented by two keys, one for the left and one for the right hand, in order to minimize finger motions between keys and, consequently, increase keying speeds.

2. The inventors of the Outertype system claim that typing on their keyboard during a certain training period leads to much higher speeds than can be obtained in the same training period on the conventional QWERTY-keyboard.

3. To verify this claim, which is based on experimental results, an experiment was done with three young adults with very little typing experience. They trained for 45 hours during 3 weeks; then, after a 5-week break, they trained for another 15 hours during 1 week. Their performance in terms of keying speed fell short of the claim mentioned, but was better than may be expected for a comparable training period on a QWERTY-keyboard. Various causes are mentioned which may be responsible, at least partly, for the discrepancy between the inventors' claim and the present experimental result.

4. The Outertype keyboard appears not to be well suited for casual users, because (i) the principle of chord keying represents an initial barrier for learning to operate this keyboard, and (ii) after a period of non-typing, it takes a while before the way of producing all letters and syllables is remembered again.

5. The subjects of the present experiment had to answer a questionnaire on their opinions about the Outertype keyboard. Their responses, together with the nature of their keying errors, indicate that this keyboard has several unsatisfactory features which may be improved.

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INTRODUCTION

The history of the development and growth of what may be euphemistically called mechanised writing is replete with many and varied attempts at developing new kinds of keyboards (see e.g. Schuurmann, 1981); all these attempts reflect the general dissatisfaction of their inventors (amongst whom must now number Den Outer & Berkelmans) with the existing machines, the most well-known of which is that based on a design by C.L. Sholes in 1873, usually referred to as the QWERTY-keyboard. Notwithstanding all the efforts of these inventors, the ubiquity of the QWERTY is self-evident to anyone visiting any office in the land. The QWERTY keyboard has limitations but continues to flourish.
One of the main disadvantages of this ubiquitous keyboard is its rather difficult operation, reflected by a long training period: a full-time typist needs a year or more to develop her highest keying speed (from Klemmer, 1971). Therefore, new keyboards which show the promise of shorter training periods and higher speeds appear attractive.
The inventors of the Outertype chord keyboard claim that for their machine, training time is shorter, higher speeds are possible very early in the training phase, and average speeds are far higher than that attainable after years of training and practice on a QWERTY. The present study was performed to evaluate Den Outer & Berkelman's Outertype keyboard with regard to these claims.

METHOD

Subjects

At the outset it was felt that a fairly representative sample of the potential user population should be used as subjects (Ss) in the experimental study but because of possible confounding effects, it was decided to exclude all those who have had typing experience. Confounding, as used here in a statistical sense refers to the unmeasurable or unquantifiable influence of one or more independent variables (factors) on the measured or dependent variable. Here, for example, previous typing experience may have a positive or negative influence on learning to type on the Outertype keyboard.

Confounding effects can be reduced, minimized or even avoided by devising suitable experimental designs. Thus, if one wished to avoid the confounding effect of typing experience, one should only use those subjects who have no typing experience. However, more information can be gained by including typists and non-typists. In the former category, skills could vary and this should be reflected in the sample. The subjects should therefore include those whose speeds could be considered as "slow", "medium" or "high" according to some pre-determined criteria.
Similarly, if one wished to avoid the confounding effect of age, only subjects of approximately the same age should be used. But it is also possible to include age as a factor in the experimental design. In the same way, it is possible to include gender as a factor.
Furthermore, if intrinsic manual dexterity is considered to be an important determinant of learning to type on the Outertype keyboard it should also be included as a factor.
Another important variable may be the level of motivation of the subjects; this possibly could be increased by giving suitable incentives but there is no guarantee that incentives can motivate all subjects.

If most of the factors attended to above are incorporated into the study a suitable experimental design would look like:

				TYPING EXPERIENCE				
				No typing experience	Previous typing experience			
					Low speed	medium speed	high speed	
Gender	Male	Age	16-24 years	3	3	3	3	
			24-32 years	3	3	3	3	
			> 32 years	3	3	3	3	Subjects required = 72
	Female	Age	16-24 years	3	3	3	3	
			24-32 years	3	3	3	3	
			> 32 years	3	3	3	3	

Table 1: Experimental Design for a 3-factor experiment

Table 1 shows a 3-factor experimental design, the three factors being gender (2 levels - male + female), typing experience (at 4 levels) and age (3 levels). The number 3 appears in each cell and indicates the number of subjects required for each particular condition. Thus, a total of 72 subjects would be required.

The use of the so-called incomplete block design technique can reduce the number of subjects required; it is also possible to reduce the number of subjects required to half by excluding gender as a factor and using, say females only. Even with 36 subjects it is still possible to examine the influence of gender by randomly assigning males and females to the different cells. If 36 subjects were used, and each subject trained for 60 hours, at the rate of 3 hours per day + 1 hour's break, yielding a total of 80 hours per subject, the total time required of the subjects would be 2880 hours. If 3 subjects could be run at the same time, the total experimented time would be 960 hours for data acquisition alone! A reduced design which would still leave many questions unanswered would be something like:

		TYPING EXPERIENCE		
		NO TYPING	PREVIOUS TYPING	
Age	16-24 years	3	low-med. speed 3	high speed 3
	30-38 years	3	3	3

Subjects required = 18

Table 2: Experimental Design for a 2-factor experiment

In view of the conceivable applications of this chord keyboard, typing experience would appear the most important factor, leading to a minimum number of 6 subjects. However, the limited number of available keyboards: 3, as well as the limited time and funds for paying the subjects led to the final choice of 3 subjects, 2 female, 1 male, without any substantial typing experience. Two of them, 19 and almost 17 years old, were still at secondary school (having just completed class 4 of the Atheneum), the third one had just finished the HAVO secondary school and was 19 years old. All were looking for summer vacation employment and regarded their 4-week participation in the experiment as a job.
A test of manual dexterity while extremely useful could not be given because of non-availability of equipment.

Equipment

3 Outertype chord keyboards, each connected to a display (18 lines x 40 character positions) and a cassette-recorder for recording of the material shown on the display-screen as well as the periods between successive chord strokes. Each set of equipment was located in a booth, which also served to separate the subjects from each other. Fig. 1 shows the lay-out of the keys. The key-tops bear a letter symbol or a special symbol denoting a part of a letter. The chord principle for the generation of syllables is reflected in these special symbols, i.e., if two keys have to be depressed at the same time to generate e.g. the letter b, they may show pictograms meant to memorize easily the letter concerned, e.g. P + ʎ together forming B , r + n together forming m , or _ + r together forming V . Table 3 shows the keys of the Outertype keyboard used for generating letter groups and for generating all letters not represented by single keys.

Table 3: The formation of: letters which are not represented by single keys, and letter groups (at the left of the = sign) by Outertype keys (at the right of the = sign)

a = o + i	or a
b = p + j	
d = t + j	
g = j + c	
h = j + l	
m = r + n	
v = r + l	or f + j
w = j + n	
x = z + k	
q = f + c	
oo = (o + e) left	
aa = (a + e) left	
uu = (u + e) left	
ie = (i + e) right	or (i) left + (e) right
oe = (o + e) right	
rc = (r + k) right	
pk = (p + r) left	or (r + p) right
tr = (t + k) left	
ft = (t + f) right	
dr = (d + n) left	
br = (b + n) left	
gr = (g + n) left	
vr = (f + j + n) left	
vl = (f + j + l) left	

th, ch, sh, etc. = lower left large key + t, c, s, etc.

ij = (i) left + (i) right

tw = (t + r + l) left

zw = z + v

cht = (c + k + z) right

ts = (t + z) right

The double representation of the consonants and vowels is supposed to be advantageous for rapid (chord) keying: the left set of consonants is used for consonants at the beginning of syllables, the right set for consonants at syllable ends. Likewise, the two sets of vowel keys are used for vowels at syllable ends or -beginnings, respectively. The "chord principle" means that whole syllables are generated for each depression of a combination of keys ending or beginning with a vowel. The basic premise behind the concept of all chord keyboards is that minimization of finger motions between keys will increase the overall keying speed.

An important feature of the Outertype keyboard is that spaces are automatically produced after each key-chord, so between monosyllabic words the typist never has to worry about keying a space. However, he does have to worry when typing a multisyllabic word: then he has to prevent a space between each pair of syllables by depressing the appropriate key, with the palm of his right hand.

For further information on the operating principles of the Outertype keyboard, the reader is referred to the training manual belonging to it (Berkelmans and Den Outer, 1980).

Procedure

All three subjects were given a passage to type on an electric QWERTY typewriter and the time taken to complete the passage was noted, from which their typing speeds were determined.

The subjects were next given a demonstration on the Outertype keyboard.

Any questions relating to the keyboard from the subjects were suitably disposed of. Each subject was handed a copy of the training material. The training material was that provided by the inventors of the keyboard. The training sessions were interspersed with rest pauses. The period of training between rest pauses varied, being 1 - 1½ hours. The rest pauses varied between 10 - 25 minutes. The duration of training was noted and at suitable moments the subjects were given speed tests. The speed tests consisted of typing a given passage as quickly as possible. The first of these tests took place after about 5 hours' training. The overall time taken for typing the test passage was measured with a stopwatch.

As the subjects did not all start their training each day at the same time or finished at the same time, the point in the time domain at which the tests took place varied slightly between subjects.

Subjects were specifically asked to practise blind-typing but it became evident from close observations that they were not performing "blind-typing" even after 20 hours of training. Thus after the fourth speed test, which was given in the latter part of the 23rd hour of training, the key-tops were removed so as to induce the subjects to practise blind-typing, which the inventors of the manual claimed was an important requirement in the training.

The key-tops were replaced at about the 42nd hour of training; this was undertaken to see if there would be a significant improvement in speed when the key-tops were available. The subjects had their 14th and last test just after 45 hours of training were completed, after which the subjects had a 5-week break. On their return, the subjects were given three tests. The first two involved typing two different passages without key-tops in place and the third test was undertaken after they were replaced. Thereafter, the subjects continued with the training using the training material provided to them. Each day the subjects were given two speed tests, one just after the start of the training for the day and the second towards the end of the training for the day. A total of 15 hours of training spread over 5 days constituted the last week of training.

As to errors detected by the subjects themselves during training, they were asked to stop typing immediately after an error was detected, and then re-type the letter or word concerned, without using the correction keys of the keyboard because then the erroneous keystrokes would be erased from the keyboard memory and, therefore, not recorded on tape. The experimenters had planned to analyse all recorded information, including errors, to investigate possible difficult spots of the Outertype keyboard.

For the test sessions, however, the subjects were instructed to type the given test material as quickly as they could making no mistakes. They were told to ignore any errors they made during the tests as efforts at correcting these errors may reduce speed considerably.

RESULTS

Unfortunately, the haste with which the experiments had to be prepared - all equipment arrived at the IPO one day before the experiment started, without proper ball-of-the-thumb keys and with only one set of key-tops whereas three sets were needed - led to some faults in the software which was meant to properly record all experimental data on cassette tape. Several efforts in Apeldoorn to correct these faults during the experimental period were unsuccesful; therefore no useful information could be recovered from the cassettes.

Keying speeds

Fortunately, the availability of the stopwatch data made it possible to monitor the learning progress of the subjects at least coarsely. Table 4 shows individual and averaged keying speeds from the test passages, expressed in 'equivalent characters' per minute, i.e., if a test passage of 52 characters was typed in 60 seconds, either on a single-stroke QWERTY-keyboard or on an Outertype chord keyboard, the obtained speed was 52 char / min. The speed scores are not corrected for errors. Also shown in Table 4 are the individual and averaged times, expressed in hours, the subjects had trained up to the test concerned.

Table 4: Keying speeds of the three subjects plus averaged values during the whole training period. No training or testing took place from 18 July until 23 August.

Date	TEST NO	Subject 1 (male, 19)			Subject 2 (female, 16)			Subject 3 (female, 19)			Mean speed		Mean time		
		speed	time	total time	speed	time	total time	speed	time	total time	$\bar{s}$	SD	$\bar{t}$	SD	Mean total time
29/6	QWERTY	112.3	0		83.7	0		112.3	0		103	16.5			
1/7	1	35.0	(4.58 hrs)		33.0	(4.58 hrs)		39.9	(4.58 hrs)		36.0	3.6	4.85	0	
2/7	2	35.8	10.25		35.5	10.25		44.7	9.95		38.7	5.2	10.15	.17	
7/7	3	48.9	17.59		50.6	17.69		70.8	17.59		56.8	12.2	17.62	.06	
9/7	4	83.7	23.75		91.2	23.95		94.0	23.85		89.6	5.3	23.85	.10	
		KEY-TOPS REMOVED													
9/7	5	33.1	23.88		37.9	24.09		50.4	23.98		40.5	8.9	23.98	.105	
10/7	6	33.7	27.16		43.8	27.32		69.2	27.26		48.9	18.3	27.24	.08	
13/7	7	48.8	30.45		43.6	30.66		87.7	30.64		60.1	24.1	30.58	.115	
14/7	8	55.0	32.45		54.8	32.66		85.5	32.64		65.1	17.7	32.58	.095	
15/7	9	64.7	36.72		59.2	36.68		95.0	36.66		73.0	19.3	36.69	.03	
15/7	10	68.8	38.88		50.2	38.84		90.6	38.83		69.9	20.2	38.85	.03	
16/7	11	72.8	40.56		68.0	40.52		123.8	40.51		88.2	30.9	40.56	.03	
16/7	12	80.6	42.88		66.3	42.84		102.4	42.83		83.1	18.2	42.85	.03	
		KEY-TOPS REPLACED													
17/7	13	94.4	44.63		86.6	44.59		108.6	44.51		96.5	11.2	44.58	.06	
17/7	14	108.3	45.80		89.2	45.76		134.5	45.76		110.7	22.7	45.77	.02	
		KEY-TOPS REMOVED													
24/8	15	36.3	0.0 =	45.80	37.5	0.0 =	45.76	53.4	0.0 =	45.76	42.4		0	0	45.77
24/8	16	48.1	0.63	46.43	53.0	0.61	46.37	57.2	0.47	46.23	52.8		.57		46.34
		KEY-TOPS REPLACED													
24/8	17	86.0	1.17	46.97	79.7	1.04	46.80	81.6	0.77	46.53	82.4	3.2	.99	.20	46.76
24/8	18	86.2	1.40	47.20	88.4	1.33	47.09	91.2	1.02	46.78	88.6	2.5	1.25	.20	47.02
25/8	19	97.1	2.80	48.60	92.2	2.80	48.56	106.1	2.45	48.21	98.5	7.1	2.68	.20	48.45
25/8	20	97.7	3.94	49.74	93.0	3.90	49.66	122.0	3.58	49.34	104.2	15.6	3.81	.20	49.58
26/8	21	100.4	7.19	52.99	91.7	7.14	52.90	131.2	6.83	52.59	107.8	20.8	7.05	.20	52.82
26/8	22	109.7	8.52	54.32	102.5	8.47	54.23	128.4	8.16	53.92	113.5	13.4	8.38	.22	54.15
27/8	23	120.8	9.30	55.10	107.4	9.25	55.01	136.4	8.90	54.66	121.5	14.5	9.15	.22	54.92
27/8	24	117.2	11.60	57.40	110.0	11.52	57.28	132.6	11.16	56.92	119.9	11.6	11.43	.23	57.20
28/8	25	129.6	12.75	58.55	107.5	12.52	58.28	132.8	12.37	58.13	123.3	13.8	12.54	.19	58.31
28/8	26	120.4	15.00	60.80	110.8	15.00	60.76	137.8	14.80	60.56	123.3	13.7	14.93	.12	60.70
28/8	QWERTY1	129.9			73.8			116.3							
28/8	QWERTY2	144.2			88.8			103.0							

The two QWERTY tests on 28 August were given before the Outertype training programme of that day.

FOR OUTERTYPE : GEEN AANSLAGEN
MAAR GEGENEREERDE
KARAKTERS

Graphical representations of the data from Table 4 can be found in Figs. 2-7. Figs. 2-4 show the keying speeds of our three subjects as a function of duration of training. It can be stated that all subjects have learned to operate the chord keyboard, but not at impressive speeds: the highest chord keying speed obtained by subjects 1, 2 and 3 was, respectively, 15%; 32% and 23% higher than their respective pre-experiment speeds on QWERTY.

Also apparent from these figures is the large influence of visual feedback: the speed of all subjects dropped dramatically after removal of the key-tops, before test no. 5. Moreover, after more than 20 hours of training without the key-tops, still all subjects showed an increase in keying speed when the key-tops were replaced, just before their holiday break.

After this break, the first two tests were given immediately after each other, without key-tops (being the severest form of retention check). Figs. 2-4 show, not surprisingly, an even more drastic drop in performance than at the first key-tops removal, because there is the added effect of forgetting now. However, performance at the second test had already improved, an improval which was continued strongly after the key-tops were replaced again.

Fig. 5 depicts the average performance of the three subjects before the holiday break, combined with the alleged QWERTY learning curve. In Fig. 6 the data obtained in the final week of the experiment are added. They show that, with visual feedback, the average performance at the end of a 60 hour-training period is levelling off, somewhat above the QWERTY curve.

The foregoing data were replotted in Fig. 7, with the specific aim of comparing them with a graph from the training manual, representing five subjects of Berkelmans. This is curve 'O'; curve 'IPO' represents the data from our subjects whereas curve 'QWERTY' is also reproduced from the training manual. Added to Fig. 7 are some data from a well-trained typist from Data Systems in Apeldoorn, with a QWERTY performance of 411 char/min. Her learning curve lies above curve 'O', possibly because of her very skilled QWERTY typing. It is interesting to note that while training part of the day on the Outertype keyboard she experienced no adverse effects on her normal task of QWERTY typing (on the same days).

Errors

When it became clear that no keystrokes, right or wrong, were being recorded, some Polaroid photographs were taken of the screens with the production of each subject, to analyse their errors. However, this is a rather cumbersome procedure; we therefore resorted to copying the screentexts on paper, and compared them with the concepts from the training manual. Thus, only an impression could be obtained of the error production towards the end of the training period.

For subject no. 1, error data were obtained from Day 16 and Day 19 of the experiment. The data from Day 16 comprise 40 errors in 802 'equivalent characters', i.e., an error percentage of 4.99%. As to Day 19, the penultimate day of the experiment, he made 47 errors in 2690 equivalent characters, i.e. an error rate of 1.75%.

Subject no. 2 on Day 19 made 24 errors in 2680 equivalent characters, i.e. an error rate of 0.90%.

Finally, subject no. 3 on Day 19 made, during normal training, 24 errors in 2810 equivalent characters, i.e. an error rate of 0.86%. At the end of her final speed test on Day 19, she made 3 errors in 315 equivalent characters, i.e. an error rate of 0.95%.

It is difficult to predict what the error rate of our subjects would have been if training had been continued. An error percentage around 1 is quite high, compared with that of a moderately skilled QWERTY typist. Obviously, a word processor apllication of the Outertype keyboard would make error correction a relatively easy job.

Of the 138 errors obtained in this fashion, three types take care of 20% of all errors, viz.:

15 space errors (superfluous spaces + missing ones),

7 m - w confusions, and

4 m - v confusions.

Interviews

The subjects were interviewed twice, once during and once at the end of the experiment. They were asked questions from a pre-prepared questionnaire on ease of operating the Outertype keyboard, specific difficulties with particular keys or letter(group)s, if any, etc. During the interview, they were alone with the interviewer.

The most important conclusion which can be drawn from the interviews is that there is quite a bit of room for improving the Outertype keyboard, within the boundaries of the chord principle. This is of course evident for a new piece of equipment, but the remarks of our subjects - to a large degree in mutual agreement - point to some specific weaknesses:

1. ʎ, r, ∟ and n are so frequently needed, i.e. have a rôle in so many chords that confusions occur, mainly between m and w, h and w, m and v. Subject no. 3 remarked that she <u>had</u> to look at the keys for making h, m, v and w, it was impossible to "type them blindly".
2. Two subjects (no. 2 and 3) sometimes had difficulties in avoiding to depress the lower right hand keys (like E , r , n , ∟) when they wished to use the upper right hand keys (like O , K , | , ʎ) together with the connection key (which has to be depressed by the palm of the right hand). Subject no. 3 thought that a little displacement of the connection key, viz. towards the right and up, possibly would prevent this problem.
3. Subject no. 1 had nothing against the position of the connection key and its left-hand counterpart, but he did object to the fact that both have several functions, in different contexts: this leads to confusion of the functions. This is related to more general complaints of himself as well as of subject no. 2 on the multi-function character of the keys used for generating punctuation marks and digits (it was called 'cumbersome' that for generating ? and ! one first had to depress the $\frac{W}{T}$ key, then the keys concerned and finally the upper case key, before continuing.
4. The automatic generation of spaces (after chords) and upper case (after a period) has its drawbacks. Subject no. 3 had difficulties with both, e.g. when typing abbreviations like b.v., o.a., d.w.z. (in such cases the automatic generation of upper case is suppressed with the same key used for creating upper case in other circumstances then after a period).
5. Apart from the letters which are easily confused, a second class of letters or letter combinations is called difficult: those which seldom occur, like x, z, dw. Subject no. 1 said at the final interview that he still did not know those keys by heart.
6. When asked about their prognosis for a further speed increase if training were to be continued, subject no. 1 expected a limit from his fingers getting 'entangled'. Already towards the end of the experimental period he had experienced that "his left hand was not yet ready when his right hand already started again". The result was a 'collision' between his left and right fingers.

Some other general remarks were about having forgotten the functions of some or all keys after the holiday break, and about the dullness of the training and testing material.

DISCUSSION

On possible differences in training procedures and subjects

The present experiment was done to investigate the merits of a particular type of chord keyboard, viz. that constructed according to the ideas of Den Outer and Berkelmans. The central issue investigated was: can typing be learned substantially faster on this keyboard than on the QWERTY keyboard, as is claimed by the inventors?

The results of our experiment as shown in Fig. 7 in comparison with (1) a curve representing the averaged results of five subjects, as presented in the Outertype training manual and (2) a QWERTY learning curve, do not corroborate the claim. So it is necessary to investigate possible causes for the discrepancy between the inventors' results and ours. The following possibilities may be distinguished:

1. presence or absence of visual feedback. We found rather large effects of taking the keytops, which designate the function of the keys, off or putting them on again. But even keys without keytops provide some visual feedback as to the fingers' position on the keys. When a typist is not looking at the keys, he has to rely entirely on proprioceptive and tactile feedback to determine the position of his fingers on the keys. Most (QWERTY) typing schools rely on using "blind" keys, i.e. without letter markings, to induce the pupils to learn to type blind. Blind typing is reported to lead to higher keying rates; it certainly leaves the eyes free to look at a text which has to be typed, or at the typed output. It may be more difficult to type blind on an Outertype- than on a QWERTY-keyboard because of the fact that combinations of several keys have to be depressed simultaneously, so getting the correct tactile and proprioceptive feedback may be more critical. In passing, it should be noted that this difference between single-stroke and chord typing, especially when

the latter involves handpalm movements as with the Outertype keyboard (for depressing the connection- or "no-space" key, for instance) by itself already represents an object for ergonomics research.
Now, it is conceivable that the subjects whose performance is represented by curve 'O' managed to type without visual feedback; more specifically, it is conceivable that their (early) training, having been without visual feedback, enabled them to develop greater keying speeds later on. On the other hand, it should be realised that especially early training with an Outertype keyboard is rather difficult, since all key combinations have to be mastered then, and to do so without any visual aids must require a high degree of motivation.

2. speed-accuracy trade-off. The psychological literature on reaction time experiments has provided many examples of this trade-off, meaning that a subject to a certain extent is free to choose to perform a task rapidly, making many errors, or slowly but error-free. Our subjects made not many errors - at the end of the experiment, samples of their performance showed an error rate around 1% equivalent characters. We know nothing about the errors made by the five subjects from curve 'O', but it is possible that their error rate was high, and, therefore, their speed higher than it would have been if their error rate also had been 1%. However, the range in speed variations for varying error frequencies reported in the literature is not high enough to explain the difference between curve 'O' and the data from our three subjects, curve 'IPO'.
   Fig. 6 also shows the Outertype-learning curve for one subject (secr.) who was, unlike the three IPO-subjects, very well trained in typing: her speed on a QWERTY-keyboard was 411 char./min. Her chord typing speeds are even in excess of those from curve 'O', but she made many errors, never bothering about them. When training, our subjects on the other hand stopped after having discovered an error, and retyped the word or letter combination concerned. This was done at the explicit request of the experimenters at the beginning of training, who then believed that all information on individual keystrokes could be recovered from a tape recording. Anyhow, since our subjects were school children, they probably would have had trouble in neglecting errors which they were aware of. But, it is conceivable that neglecting errors made during the first phase of learning to type on a chord keyboard would be advantageous for the keying speed developed later on.

3. differences in text composition. The IPO subjects were trained and tested with text material from the Outertype manual. It is possible (though not very likely) that all tests which the subjects had to type in the later part of the experiment were intrinsically more difficult than the tests in the beginning, and therefore took relatively longer. Secondly, it is possible that the subjects from curve 'O' were tested with easier texts then the IPO subjects. Finally, it is conceivable that the tests from the QWERTY-curve in Fig. 7 refer to text material of lower difficulty than those of the curve 'IPO'.
4. auditory vs. visual text presentation. The subjects from curve 'O' were dictated their text material, by a cassette recorder running at a certain speed (see 5). The subjects from curve 'IPO' on the other hand were reading their texts, and thus switching their eyes from a VDU to the manual vice versa. Now and then they may havehad to search for the correct place on the paper where to type: this would have cost them some time in comparison to the subjects from curve 'O'. In fact it was found that the IPO-subjects for short stretches of text keyed at a speed up to 75% higher than their average speed for a whole piece of text - but this in itself is no proof of them losing a substantial portion of time searching on the manual page at hand.
5. paced vs. unpaced text presentation. Our subjects were allowed to type at a pace they chose for themselves, i.e., they were unpaced by the experimenters. Contrary to this, the dictation speed of the subjects from curve 'O' was gradually increased, in fixed steps, so that these subjects were forced to type at their current top speed.
6. motivation differences. We are not so sure that such a paced training procedure, which forces subjects to increase their speed, would have been accepted by our subjects. It appears likely that the subjects from curve 'O' were highly motivated. Our subjects were very motivated as well in the first weeks of the experiment. Later on, and certainly during the last week, after their holidays, they began complaining about the texts that had to be typed: these were considered boring, especially when they had to type certain test-texts for a second time. These comments may be taken to reflect a certain interest in the content of the texts - such an interest may have prevented our subjects to type at their ultimate speed.

Also, during the last week our subjects began to be keen on keeping exactly to their working hours, pauses, etc., whereas in the first week they had rather not had so many rest pauses as were prescribed by the experimenters.

7. massed vs. distributed training. It must be admitted that our subjects had to practice very long on one day: about 3 or even 3½ hours. In typing schools, the pupils do not practice longer than 1 or at most 2 hours per day. We do not know if the subjects from 'O' were having such distributed training, or rather massed training as we gave our subjects. It is conceivable that massed training decreases the subjects' motivation and, therefore, their performance.
   The reason for giving so much training per day was twofold. In the first place, it would have cost too much time of the experimenters if the number of training days had been extended. In the second place, it would have been extremely difficult to find subjects, even paid ones, who would be willing to come for an hour or so per day during 60 days, i.e. 12 weeks. As a matter of fact it was already quite complicated to determine one continuous period of three weeks in which three subjects all could participate, between the end of their school classes and the beginning of their holiday travel. A 5 week-break in training, like we had to accept, in principle is unfavourable for studying any learning curve, since it is hard to tell what would have happened without the break.
8. differences in talent
   Just like there are differences in manual dexterity leading to different performances on QWERTY keyboards, there will be differences in people's natural ability to type on a chord keyboard. The skills required for chord typing appear akin to the skills needed to play a musical instrument - and not everybody is able to learn to play music. So, it is possible that the subjects from curve 'O' were more talented in this respect than our subjects, e.g. because they were more or less selected. It appears unlikely, for example, that the subjects from 'O' possessed only 'average motivation' for learning chord keying, since they trained for up to 90 hours, i.e. more than 50% longer than our subjects. Moreover, they trained on a dummy keyboard, with key-tops pasted on foam rubber. Only during the tests they used real equipment.

Are the eight possible causes listed above sufficient for explaining why the IPO-subjects failed to reach the learning speed of the subjects from curve 'O'? It is not possible to answer this question with any certainty without knowing more details about the conditions under which the data from 'O' were obtained, and without having done other experiments, in which e.g. the effect of visual feedback is specifically investigated. It appears reasonable to state, though, that it will not be easy for a group of average people trying to learn typing on the Outertype keyboard, to match the performance from curve 'O'. After all, our subjects did try reasonably hard to master this skill. Especially if one thinks of non-professional typing, it appears likely that learning would not take place under more rigid conditions than those of the present experiment, and, therefore, such typing probably would progress along a learning curve below curve 'O'.

Possibilities for major improvements of keyboards

An analysis of the set-up of the QWERTY keyboard immediately leads to the conclusion that it is not optimal. For example, 55% of all keystrokes have to be done by the left hand, which is the non-preferred hand for most people. Yet, the history of proposed alternative keyboards shows only failures (Schuurmann, 1980); apparently, the fact that the QWERTY keyboard existed in large numbers was sufficient to block any further developments. Still, it is tempting to consider in some detail the possibilities for improvement. Both in the realm of biomechanics and in that of mathematical linguistics such improvements would seem feasible; however, they require thorough studies as well as ergonomics experimentation, in short, they require research.

That the Outertype keyboard has inherent weaknesses is clear, any keyboard will. The important question is: are these weaknesses as small as is possible, taking all relevant factors into account? For example: how large is the advantage of the double representation of consonant keys, for the first and the last letters of syllables, if one takes into account that one of these sets of consonants has to be keyed by the non-preferred hand, usually the left one, of the typist? See the comment from Subject no. 1.

The incorporation of a microprocessor in a keyboard offers attractive options for corrections of or additions to what is typed (like the automatic insertion of a space followed by an upper case after typing a 'period' on the Outertype keyboard). It is possible that investigating this type of innovation to the field of keying may ultimately be more fruitful than investigating novel lay-outs of the keyboard itself.

CONCLUSIONS

1. Typing on the Outertype keyboard can be learned at a speed which is at least as high as on a QWERTY keyboard, and at an acceptable error rate.
2. The principle of chord keying represents an initial barrier for learning to operate an Outertype keyboard: one cannot just sit down and type in a hunt-and-peck fashion, which is possible with QWERTY.
3. Some letters and letter combinations, produced via the more complicated chords, are easily forgotten after a period of non-typing - at least during the first tens of hours of keying experience.
4. Conclusions 2 and 3 taken together appear to imply that the Outertype keyboard is not well suited for casual users.
5. Several features of the Outertype keyboard are unsatisfactory and may be improved, within the principle of chord keying. Producing digits and punctuation marks, for instance, is rather cumbersome. Other features, like the use of the palm of the hand instead of a finger for activating a number of functions, are interesting on their own merits but require careful consideration as to their biomechanical demands.

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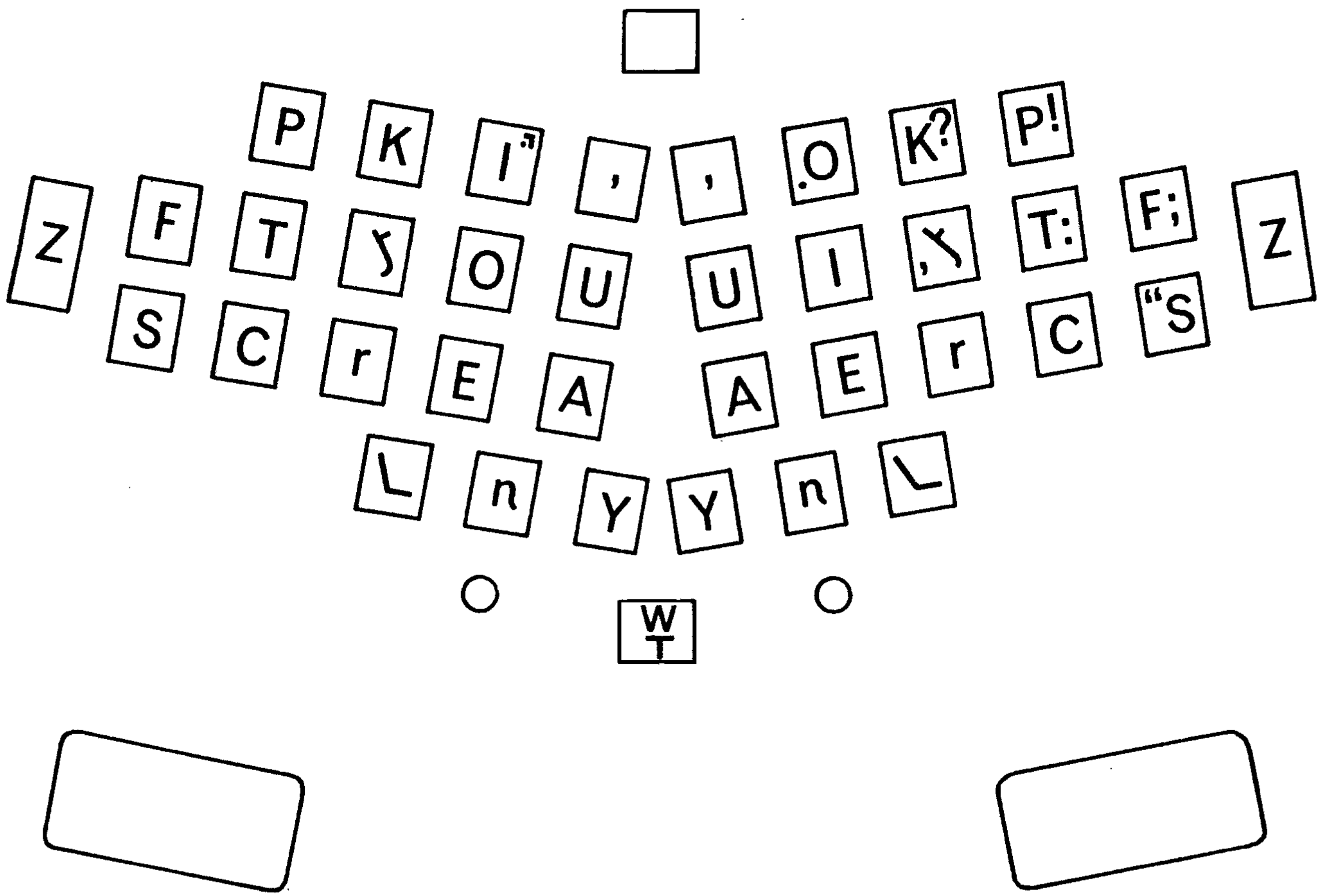

Fig. 1. The lay-out of the keys on the Outertype chord keyboard, as used in our experiment. The upper key was used for clearing the VDU screen. The two large lower keys bore no inscription. The left one was used, among other things, for generating upper case; the right one to suppress 'space'. The two circles represent micro switches without hoods which were present on the board, but could not be used as keys.

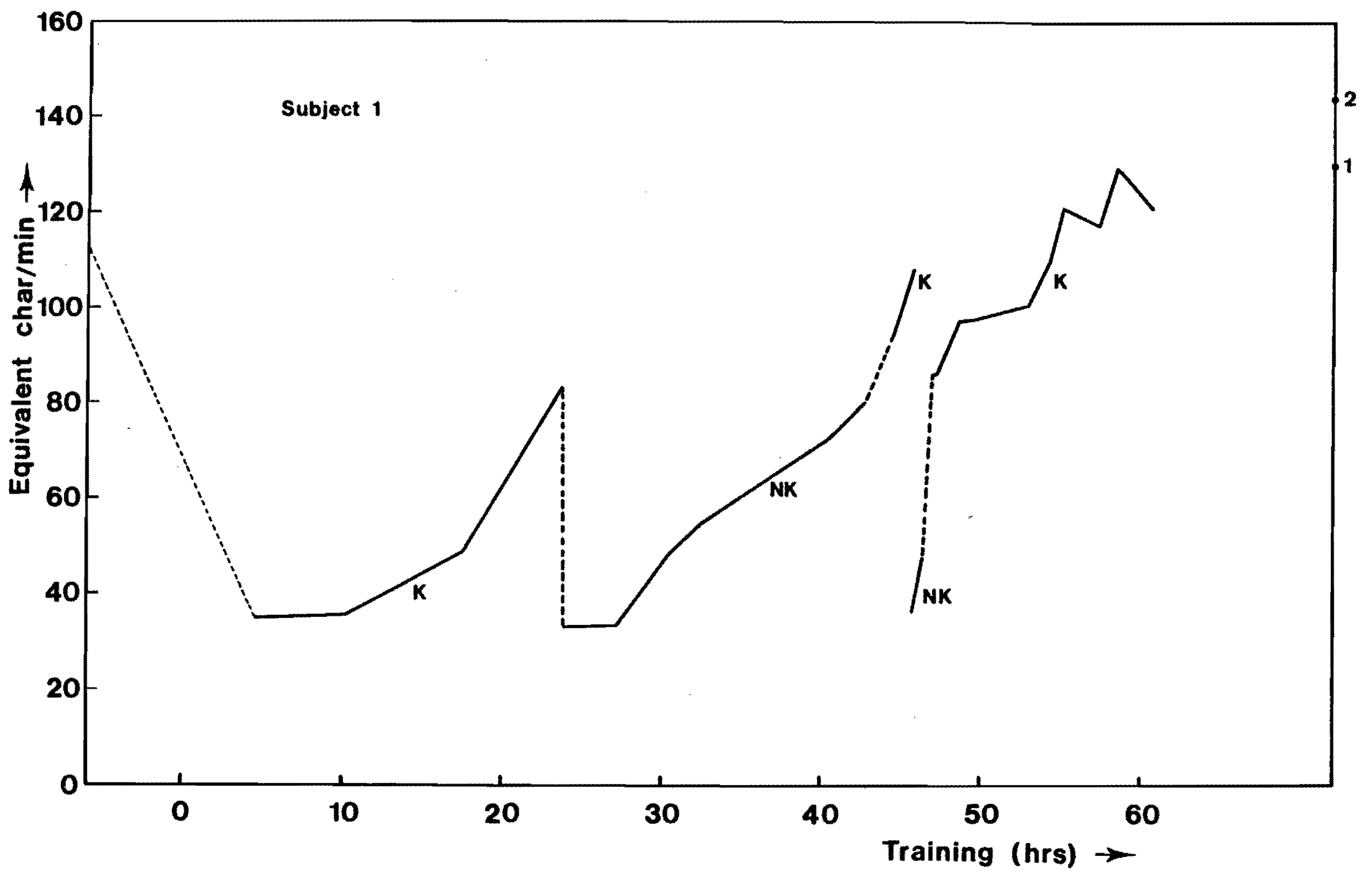

Fig. 2. Keying speed of Subject 1 as a function of training duration. The point at the ordinate refers to his QWERTY typing speed before the experiment, points 1 and 2 at the right vertical line refer to QWERTY-tests on the last day of the experiment. The break in the curve corresponds to a 5-week break in training, after 45 hours. The sections with 'K' refer to tests with key-tops, the sections with 'NK' to tests without key-tops.

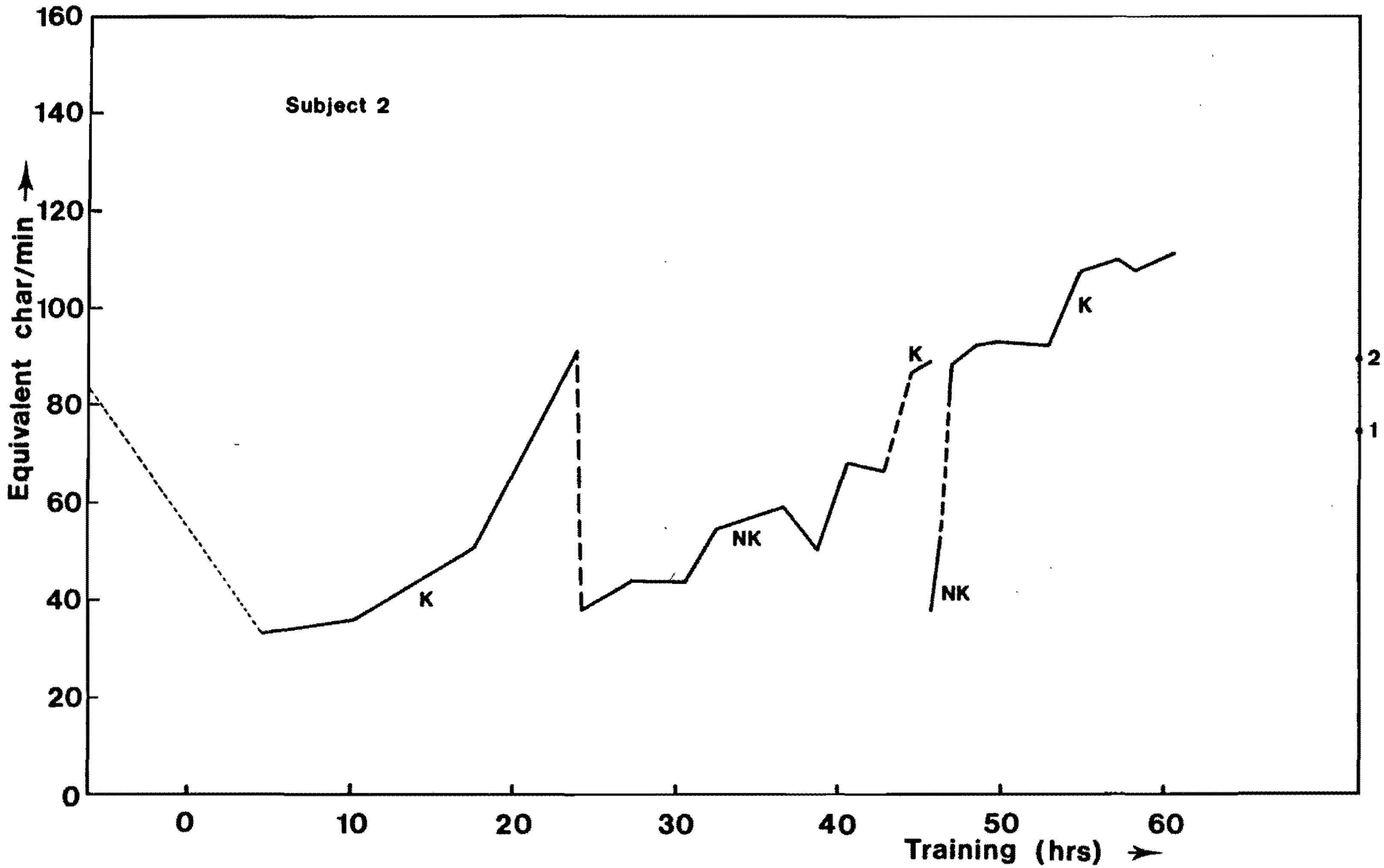

Fig. 3. Keying speed of Subject 2 as a function of training duration. The point at the ordinate refers to her QWERTY typing speed before the experiment, points 1 and 2 at the right vertical line refer to QWERTY-tests on the last day of the experiment. The break in the curve corresponds to a 5-week break in training, after 45 hours. The sections with 'K' refer to tests with key-tops, the sections with 'NK' to tests without key-tops.

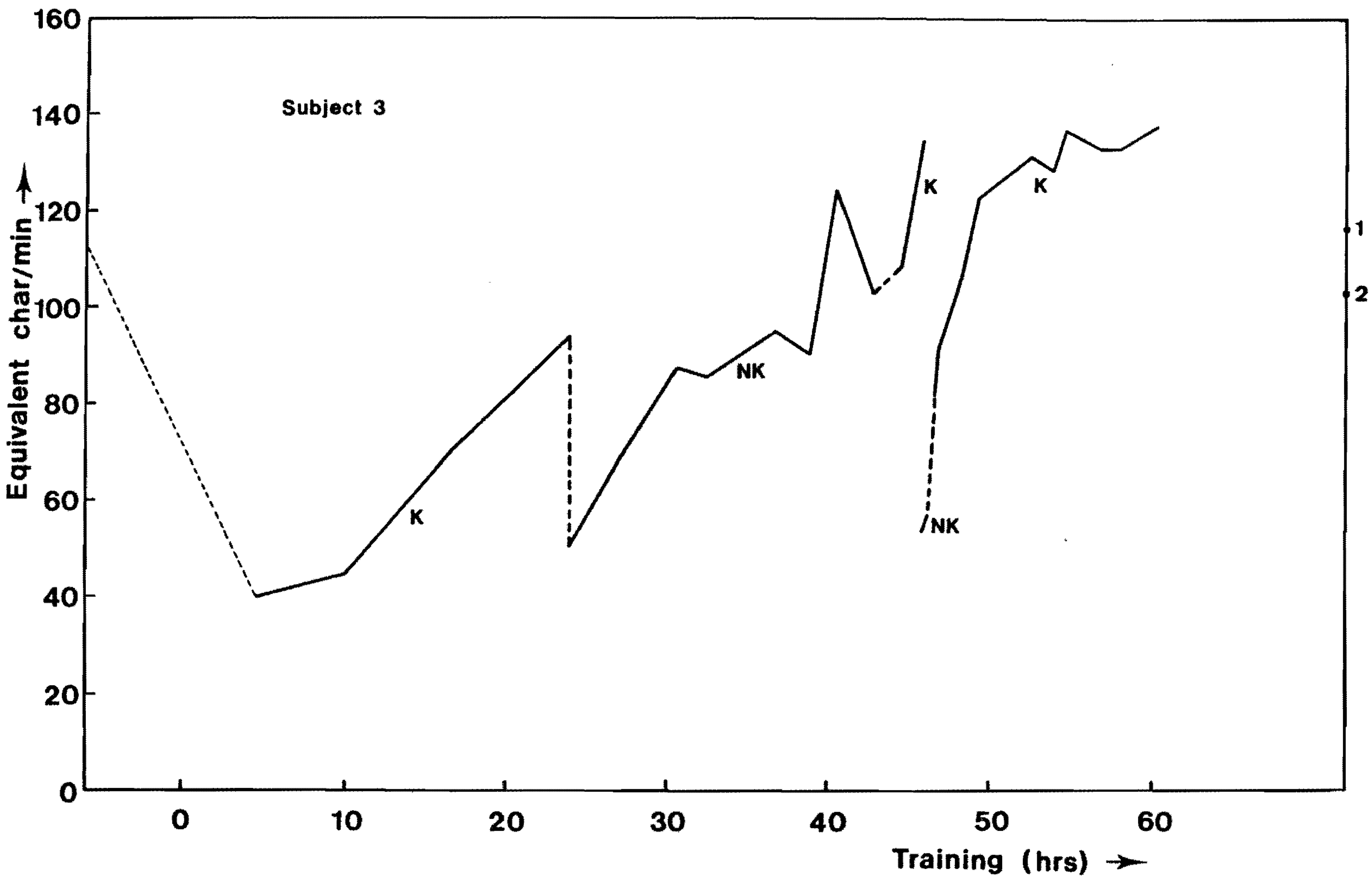

Fig. 4. Keying speed of Subject 3 as a function of training duration. The point at the ordinate refers to her QWERTY typing speed before the experiment, points 1 and 2 at the right vertical line refer to QWERTY-tests on the last day of the experiment. The break in the curve corresponds to a 5-week break in training, after 45 hours. The sections with 'K' refer to tests with key-tops, the sections with 'NK' to tests without key-tops.

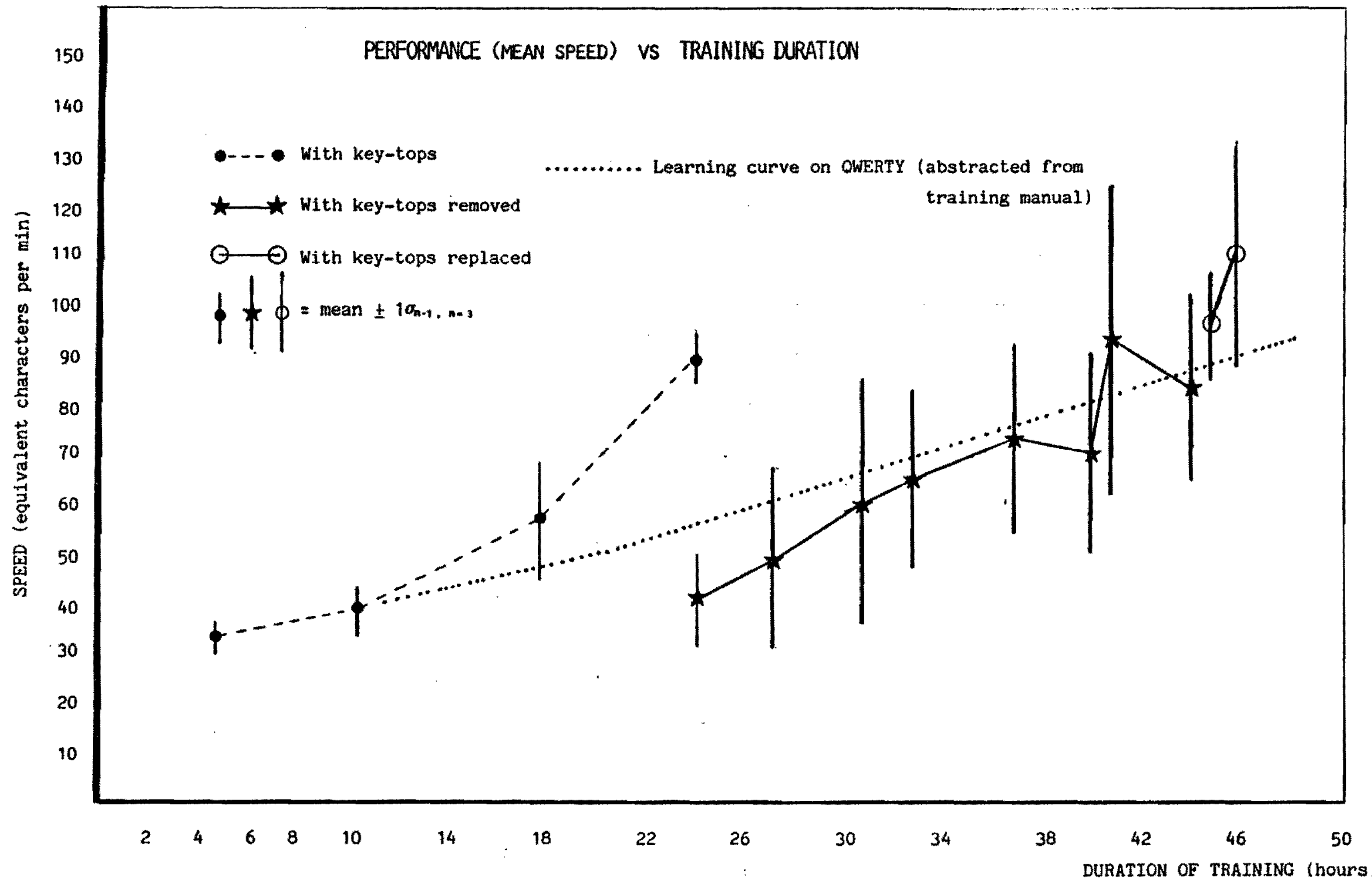

Fig. 5. Average performance of the three subjects as a function of training duration before the holiday break.

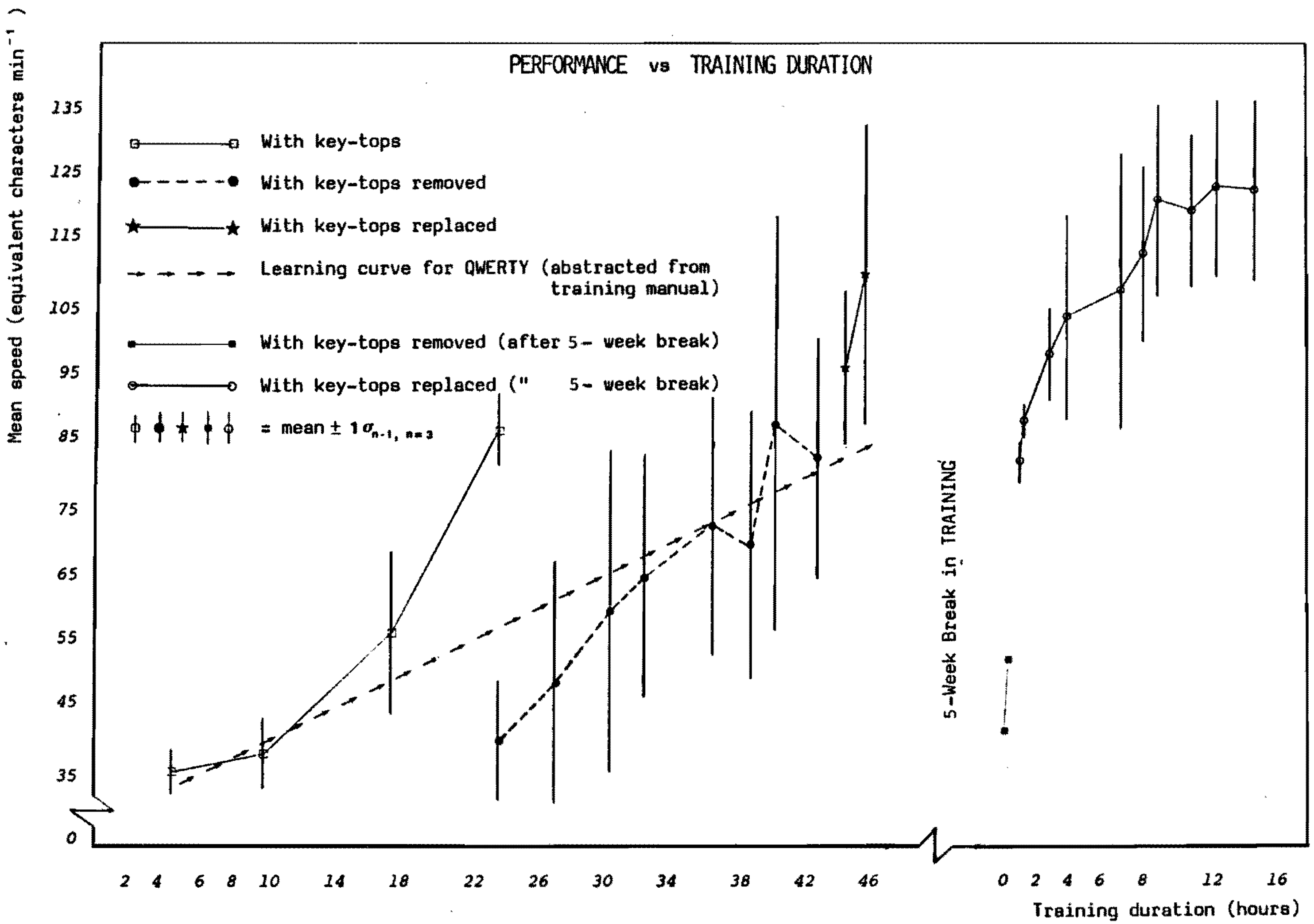

Fig. 6. Average performance of the three subjects as a function of training duration.

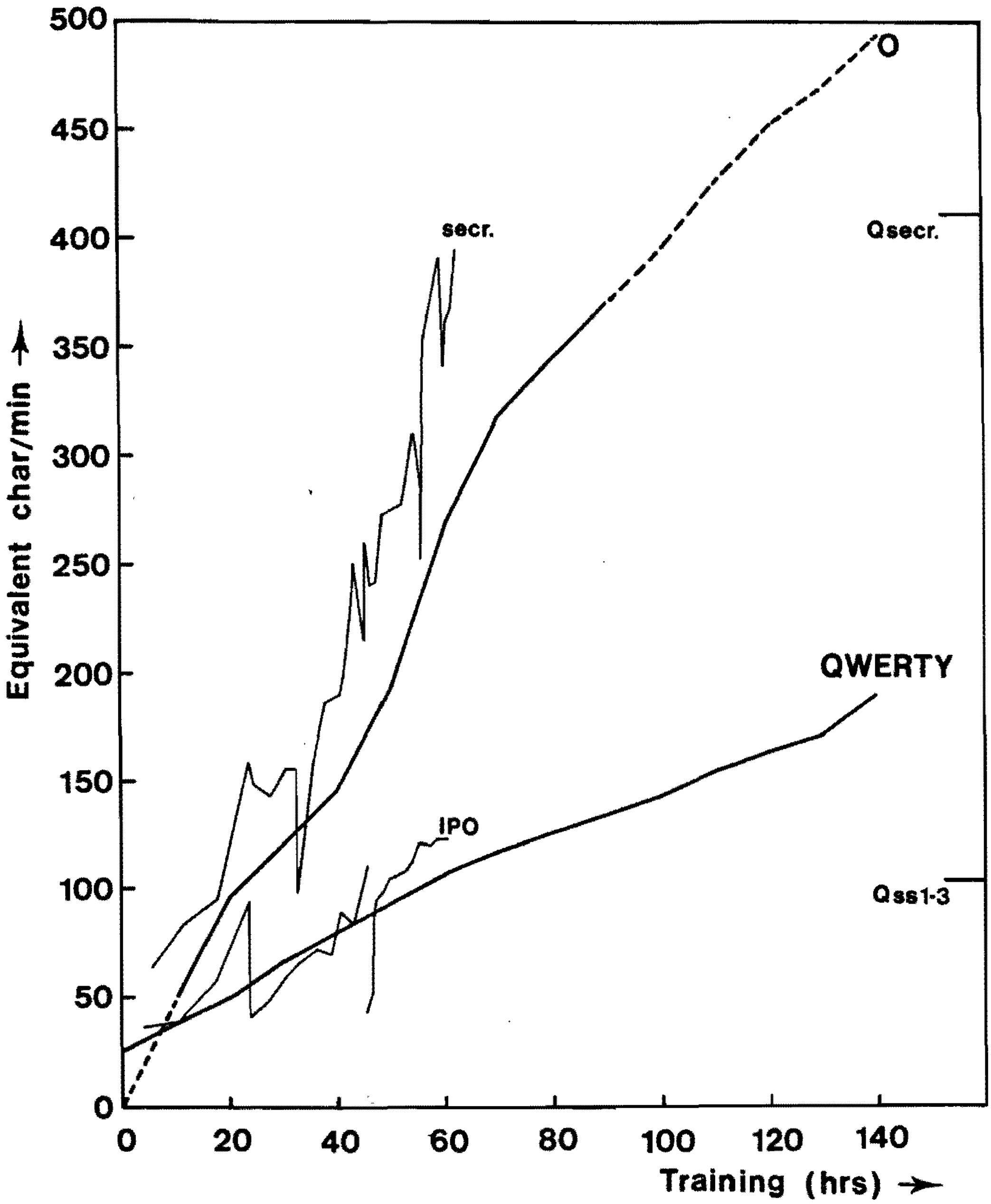

Fig. 7. Curve 'O': training results of 5 subjects trained on the Outertype keyboard, the dotted section was "estimated"; curve 'QWERTY': learning curve for a normal QWERTY keyboard (both reproduced from the Outertype training manual). Curve 'IPO': average Outertype results of the subjects from the present experiment (their average QWERTY speed is indicated with Qss 1-3). Curve 'secr.': Outertype results of a well-trained typist (her QWERTY speed is indicated with Qsecr.).

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