AN ANALYSIS OF THE STANDARD ENGLISH KEYBOARD

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Summary

A study of the nature of hand and finger motions in typing process was made, based on the data on time intervals between key strokes. Many of the results obtained confirm those formerly obtained by Dvorak and other researchers. In addition, it was found that each key sequence is affected by its context, thus proving that the mental aspects of typing directly affects its productivity. and that the performance analysis on a particular keyboard arrangement is not sufficient to predict the performance on other arrangements.
Based on these results, the current English keyboard is judged to be a less than ideal tool for typing.

1. Introduction[1]

The task of studying typewriting behavior and evaluating keyboard efficiency has been taken up by many researchers in the past. most of these had the motivation to search for an optimally arranged keyboard, and have pointed out various defects of the current English keyboard. (called *Universal*, or *QWERTY* keyboard, by the arrangement.)

The QWERTY keyboard came into existence (both shape and arrangement, leaving out a few minor changes) together with the invention of the keyboard typewriter itself (Sholes: 1873). Since the emerging of touch typing techniques around the turn of the century, it has held its established position in the Western society until today. But as soon as the QWERTY keyboard became socially prevalent, questions were raised against its efficiency. The ineffectiveness of QWERTY is an inevitable consequence of its origin. Since the most urgent problem that Sholes faced was to avoid the jamming of the then mechanically deficient typebars against each other, after trying out various arrangements, he came out, not intentionally, with an arrangement difficult to type fast on.

Well considered objections against QWERTY were voiced at least as early as 1893(Hammond). Since then, many studies and a number of suggestions for improved arrangements were made. Some of the suggestions made were those by Hoke(1921),[4] Griffith(1949),[5] Nickells(1973),[6] and Malt(1977).[7] Among them, the work done by Dvorak *et.al.*(1936)[2,3] is considered by many to be the most important of all, because of the deep psychological insight presented, and the keyboard they proposed, known as the *Dvorak Simplified Keyboard (DSK)*. Today, DSK is thought to be of a near optimal arrangement. Many reports countering to these improvement suggestions in favor of the firmly established QWERTY keyboard also appeared. The report of Strong(1956),[8] supported by GSA, gave in a way a decisive blow to the DSK, and QWERTY is still holding its firm position.

Typing is a highly complicated procedure deeply involving mental activities as well as physical movements. To cover it in its entirety would call for an immense task of human factors research, a large part of which is not yet well understood. However, when carefully examined, even a rudimentary measurement of certain factors of typing behavior would lead to a good understanding of some pertinent aspects of the typing process.

We faced the problem of keyboard optimization in the process of developing a Japanese-input keyboard. Our approach here is based on the measurement of the time interval of key strokes, obtained from the typing performance of English text by a proficient typist. In this paper, we first present the findings based on these data, discuss an important human factors problem involved in them, then attempt to present an evaluation of the QWERTY keyboard in this perspective.

2. Basic Notions

Through our experiment, we intended to obtain some understanding of the relation between key sequences and the resulting motion of hands. In other words, we wanted to know what kind of key sequences result in a *good* typing motion, as against others. Since typing (especially touch typing) is a process of consecutive reflexive motion of two hands, it would not be sufficient to study this through the motion of hitting an individual key. The ability to tap a same key fast does not directly mean that the person is a good typist. The essence of typing skill is in the ability of maintaining minimum hand and finger transitions through the keying sequence, in order to produce *good* motions. Typing speed seems to be a good measure for this, and is also appealing to our intuition. Alternate measures include the fatigue of the typist, and typing error rate. The latter will be discussed in section 6.

We mainly utilized our data on time intervals between key strokes in order to get at some aspect of hand motion. The elementary component that constitutes a key sequence is a key pair, that is, consecutive two strokes on the keyboard. Our first objective is to list the key pairs in the order of typing ease. A first order approximation for this ordering might be to put the key pairs in the order of typing speed. But our attempt in this direction immediately turned out to be futile. The time values themselves were not easily determinable from the measurement. In addition, the direct ordering gave no insight into the nature of hand dexterity. Sometimes it even appeared to contradict our intuitive notions of dexterity.

So we turned to a two-step approach instead. We first attempted to factorize the time data, and next tested certain conjectures on typing motions based on them.

Each of the interval times of keying must be a function at least of the choice of two keys forming the key pair, as well as of other factors. Thus, the time value t for a certain key pair (k_1,k_2), where suffixes 1 and 2 stand for the first and second keys respectively, may be described as:

$$t = F(k_1, k_2) + e \qquad (2.1)$$

e representing those factors that cannot be described in terms of the key pair, including probabilistic fluctuations. Keys may be subdivided according to their row, hand, and finger of operation. Thus, (2.1) may be rewritten as:

$$t = F(h_1, h_2, r_1, r_2, f_1, f_2) + e \qquad (2.2)$$

where h, r, and f stand for hand, row, and finger, respectively. These attributes of keys may interact with each other. In an exact analysis, it is not correct to handle even the finger component of both hands together, since the keyboard is not left-right symmetric in shape. But we shall ignore this fact for the present analysis.

A certain key may be referred to by the alphabet it stands for on QWERTY, or by its associated finger, row, and hand. Dictated by the design phylosophy of our system, we are mainly interested in the middle 10 keys of the upper, home, and bottom rows. The set of these 30 keys will be called the *main set*. Following Dvorak, some characteristic key pair patterns are named as follows.[2]

Hurdling:Strokes by the same hand, fingers jumping over a number of rows.
Reaching:The stroking of different keys with the same finger.
Tapping:The stroking of the same key.
Rocking:Strokes on the same hand, rolling in from the outer side of the keyboard inward.
Adjacent:Stroking by adjacent fingers of the same hand.
Remote:Stroking by remote fingers of the same hand.
Alternate:
Stroking by different hands.

The data we use here were taken from a timing experiment on the *Superwriter system* implemented on the H-10 computer at the University of Tokyo. The typing was done by a professional English typist (Japanese, female). Time intervals of key strokes were measured down to milli-seconds. Input texts were selected from the last part of "Alice in Wonderland" and the entire "Through the Looking-glass," excluding the verses ("The Annotated Alice", L. Carroll, ann. by M. Gardner), and "Information Processing" (M. Bohl), a textbook of computers. The whole data consists of 302,392 strokes, 142,262 for Alice and 160,130 for the computer text.

Being taken from the field of literature which is unfamiliar to the typist, the Alice text presented to her difficulties in:

1) The presence of special characters. The text is full of conversations, thus a good number of quotation marks are used. Also, exclamation marks, question marks appears frequently.
2) Use of unusual words and phrases (a characteristic of Carroll).

On the other hand, the computer text makes a frequent use of technical terms. The use of uncommon words results in a high rate of typing errors as we shall see in section 6. However, we could not conclude that these singularities would indeed affect the overall typing behavior differently, so both data will be treated combined.

Most of the time interval values clustered in the region between 100 and 300 ms. The data with extraordinarily large values were eliminated, using a threshold of 500 ms., because they must have resulted from some reasons other than the typing itself, such as the page turning of the text, etc.

Of the 900 (= 30 x 30) possible key pairs in the main set, 805 had actual data entries. Of them, the less frequently used key pairs showed seemingly random time-frequency distributions. Here we encounter our first problem, since the key pairs we regard of highest importance, namely, alternate hand stroking on the home row, had very few entries. As can be seen on the keyboard, these are key pairs that would seldom appear in a normal English text. Only one vowel, "a", is on this row.

General Features

1) Entries faster than 500ms.
   Entries: 294,272 Mean: 162.8 S.D.: 74.9

2) Among 1), key pairs using only the lower case.
   Entries: 180,051 Mean: 154.3 S.D.: 64.5

3) Among 2), key pairs using only the main set.
   Entries: 179,137 Mean: 153.8 S.D.: 64.0

3. Distribution of Individual Key Pairs

Distribution graphs of various types of key pairs are given in Figures (3-1) through (3-6). Figure (3-1) is an example of an alternate key pair, (3-2) of an adjacent, (3-3) of a remote, (3-4) of a tapping, (3-5) of a reach, and (3-6) of a hurdle. Brief general observations of all of the key pair distributions are:

1) Most mean values range from 100 to 200 ms.
2) There is a lower bound for time intervals. (or, saying the same thing from the other side, an upper bound of typing speed of a key pair.) This bound falls somewhere between 60 and 80 ms. Thus, we think that 60 ms. is the lower bound for keying intervals. (1,000 strokes/ minute)
   The distribution of the bound is different of that of the mean values, and the range is narrower. In fact, it is generally smaller for adjacent key pairs, though the mean value of their time is comparatively larger. Reaches and Taps, that is, key pairs that use the same finger, are exceptions to this. For example, key pair "d-e", a reach key pair, has a lower bound greater than 100ms.
3) The peak of the graph is skewed to the left, with a long tail. That is, the median is seen to be always smaller than the mean, and the skewness factor (=normalized third order moment around the mean) is positive.
4) Skewness decreases for key pairs with larger mean time values. It is also smaller for key pairs with less frequency in general.
5) The peak is quite pointed.

We have seen that there is a physical upper bound for typing speed of key pairs, which is nearly the same for different kinds of key pairs (except for those using the same finger). This may be thought of as the physical limit of response time intervals of fingers to the brain signals that call for separate strokes. Most strokes of a certain key pair gather around a time value close to the lower (time) bound. This means that there is constant rhythm in typing each key pair, or as we will see later, it may be better to say that nearly constant rhythm is kept within a certain span or *context*, which is likely to be a word. In addition to these basic properties of stroking patterns, there are many other factors which contribute to the whole pattern of distribution. These factors may work in an unpredictable way, and are likely to have greater effects on the key pairs that are not located in familiar contexts.

The effect of the frequency of usage is not so explicitly manifested in the distribution of individual key pairs. However, there exists a correlation between the mean time values and frequencies, which we shall see in the following section.

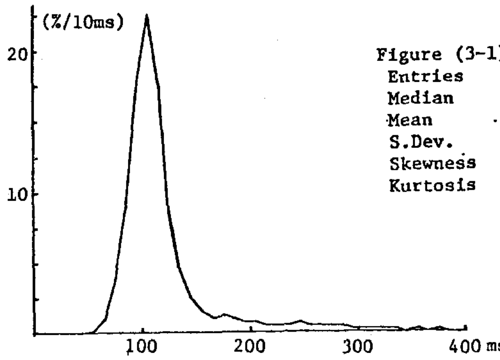

Figure (3-1) "h-e"
Entries : 6098
Median : 109
Mean : 121.5
S.Dev. : 49.9
Skewness : 3.04
Kurtosis : 14.5

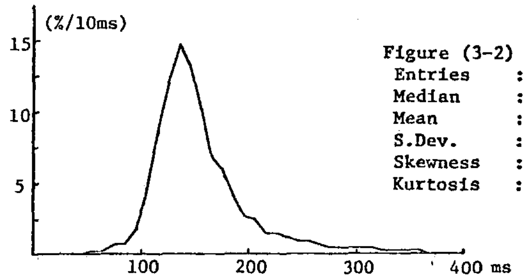

Figure (3-2) "e-r"
Entries : 3997
Median : 146
Mean : 156.7
S.Dev. : 48.8
Skewness : 1.85
Kurtosis : 8.39

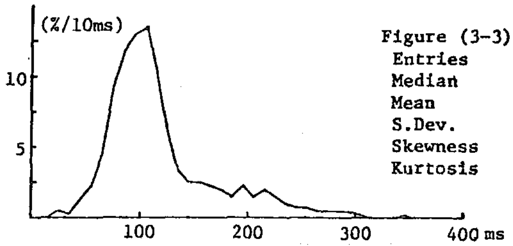

Figure (3-3) "s-t"
Entries : 1681
Median : 147
Mean : 168.8
S.Dev. : 64.3
Skewness : 1.21
Kurtosis : 4.59

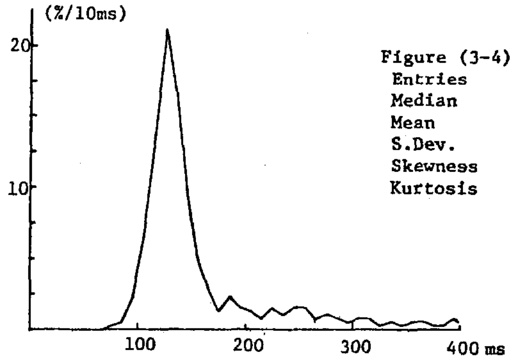

Figure (3-4) "l-l"
Entries : 1180
Median : 134
Mean : 158.9
S.Dev. : 68.5
Skewness : 2.13
Kurtosis : 7.38

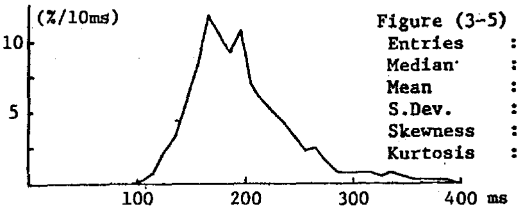

Figure (3-5) "d-e"
Entries : 1280
Median : 188
Mean : 196.8
S.Dev. : 47.3
Skewness : 1.23
Kurtosis : 5.29

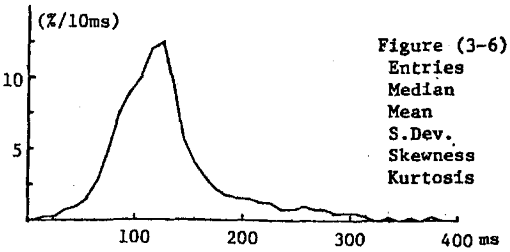

Figure (3-6) "o-n"
Entries : 2891
Median : 121
Mean : 131.1
S.Dev. : 56.2
Skewness : 1.74
Kurtosis : 7.73

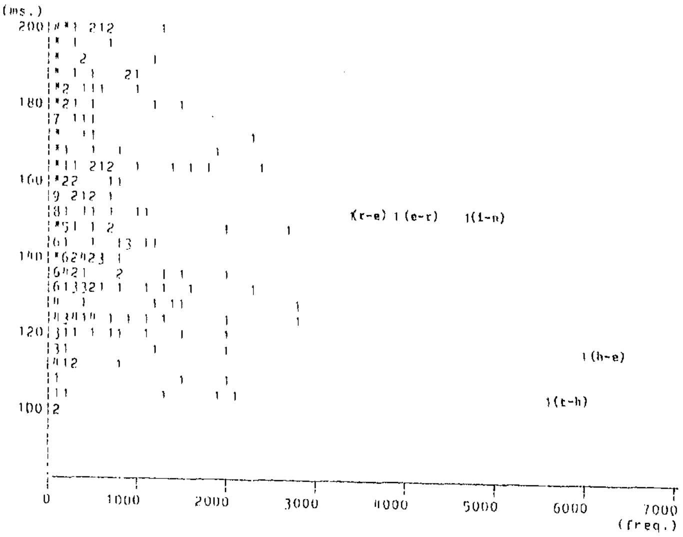

Figure (4-1): Time-Frequency Distribution of Key Pairs. (*: 10~20; #: 100~)

4. Factorization of the Time Data

Figure (4-1) shows the distribution of the mean keying time of key pairs and their frequencies of usage. The distribution of the mean interval time of key pairs and their frequencies of usage, at a first glance, appears quite dispersed and seems that there is no correlation between them. But looking at it a little more carefully, we may detect some negative correlation between the two components. We may also see that the dispersion of the mean time of key pairs is greater for those with smaller frequencies, indicating that this distribution is a result of probabilistic fluctuations. Our first task is to find out the effect of the frequency on the time data.

The fact that the correlation is negative suggests that frequent usage has some effect on the improvement of typing skill. But the meaning of this may not be as simple as it seems, because we do not know exactly what aspect of the typing process is affected. One might surmise that the keyboard arrangement of QWERTY is such that the ease of typing and the frequency of usage is in the corresponding order. thus the correlation reflects the dexterity of hand and finger motions. Of course this is not likely; at least QWERTY was not intentionally designed that way. But what is "typing skill" in this situation? This will be discussed in details in section 7, here we only note that the time-frequency correlation may not be entirely attributable to the genuine improvements of hand dexterity, since key pairs that are analogous in motion to those *skilled* pairs and are of lower frequencies are not necessarily improved in the same fashion. Thus, to keep our approach of regarding typing as a process of reflexive motion, we have to subtract out the effects of frequency on the time values, from their further scrutiny. Now, equation (2.2) becomes

$$t = F(h_1,h_2,r_1,r_2,f_1,f_2) + E(freq) + e \qquad (4.1)$$

where function E represents the effect of the frequency. Since there exists a lower bound for t, we may think of E to have some exponential feature. Taking those entries which have the frequencies of usage of more than 50 in order to eliminate the effect of random fluctuations, a reasonable exponential fit for t is

$$t = 60.5\exp(-0.00414freq) + 156.4$$

which gives the statistical lower bound of 156 ms. However, with a frequency threshold of 50, a linear least squares fitting is no worse than 10% than this exponential fit in terms of the residue of squares, so for further analysis on frequencies, we shall use linear regressions.

We further assume F in equation (4.1) to have linear property. The parameters for F are defined on the attributes of of the key pair as follows:

h: hand transition.
  0: same hand 1: alternate hand

r: row transition.
  Number of rows moved across in the same hand transition, set to 0 for alternate hand motions.

f: finger transition.
  The distance of finger columns in the same hand, set to 0 for alternate hand motions.

R: row weight.
  Linear sum of weights for each row position, where the weights given are 1, 2, and 3 for home, upper, and bottom row, respectively.

F: finger weight.
  Linear sum of weights on each of the finger positions of the key pair, where the weights given are 4.5, 4.5, 1, 2, and 3 from the outer column inwards.

Thus, (4.1) becomes:

$$t = a + b_0 freq + b_1 h + b_2 r + b_3 f + b_4 R + b_5 F + e \qquad (4.2)$$

By multi-variate linear regression, the parameters are estimated to have values as follows:

$a = 185.8$
$b_0 = -0.013$
$b_1 = -40.0$
$b_2 = 18.3$
$b_3 = -11.0$
$b_4 = 0.514$
$b_5 = 1.07$

These results are in agreement with our general understandings, that

1) Alternate hand stroking is faster than same hand stroking, and hand transition is the dominant factor. The difference is as large as 40 ms.
2) In same hand stroking, row transition causes a slowdown of around 20ms. (Row transitions and finger transitions in alternate hand stroking bear little meaning, and have been omitted from the analysis.)
3) Finger transitions do not present a clear cut picture. In general, adjacent finger stroking is inferior to remote finger stroking in speed.
4) Row weights and finger weights do not make noticable contributions, but the orderings we chose seem reasonable.

Further examinations were made by testing the significance of the difference of mean values between two types of key pairs. The results proved our conjectures on finger strength, the superiority of alternate strokes, the undesirability of awkward sequences, etc., with a reliability level of over 99%. They are in agreement with the results of Dvorak.[2]

So far the analysis has been on key pairs in isolation. That is, we have been ignoring interactions between key pairs. But it turns out that these factors, namely the e factor in (4.1), cannot be ignored, in fact they play an important role in understanding the typing process, as we see next.

5. The "Levelling" Effect

In the preceding sections, we have stated that a typist does not read text by individual key pairs or characters, but by words. This means that she is creating a queue of elementary motions somewhere in her mind (not as a conscious activity), and the actual finger motions are generated as an aggregate of the components in this queue. From this we infer that a certain optimization of the motions of hands and fingers takes place in this process.

The analysis in the preceding section was concerned with isolated key pairs and ignored interactions among them. Because of this simplification, the multi-variate model enabled us to explain only half of the residue of the time-frequency regression analysis. The rest must be a result caused by external effects, which is represented by the e factor in (4.2). So, we proceed to examine the effect of the *context* keying pairs to the time values of a key pair.

We mean by *context* the key pairs immediately preceding or succeeding the key pair under attention. A simple tallying showed that in convex situations (that is, a situation that the preceding and succeeding time values are both smaller than the present time value), and in concave situations (the opposite of the convex), the time value tends to be pulled towards the direction to relax the curvature, with respect to the mean time value of the present key pair. The effect is most significant with alternate hand stroking, where 87% of the time values in a convex situation are pulled downwards, and 59% in a concave situation are pushed upwards. This means that the context is more effective to increase the overall speed rather than to slow it down, though this is the opposite to our initial expectation. At any rate, our hunch that the time interval of consecutive key pairs are smoothed, or *levelled*, seems correct.

A more detailed analysis confirmed the qualitative claim made above. Naming the preceding, present, and succeeding time values t_1, t_2, and t_3, respectively, the correlation of

$$T_1 = (t_2 - t)/s$$
$$T_2 = ((t_1 + t_3)/2 - t)/s$$

was calculated, where t is the mean, and s is the standard deviation of the present key pair. T_1 has a (0,1) distribution. The distribution of T_2 is unknown, although it is in a sense normalized with respect to T_1. Counting all the cases, the correlation coefficient of T_1 and T_2 is 0.4325, while for convex situations this is 0.6701 and concave 0.5910. The concave one improves to 0.6282 for alternate stroking, while convex-alternate is 0.6479 in this case. These values of coefficients suggest a strong positive correlation between T_1 and T_2, especially for the convex and the concave, or *popped out* cases. The result that alternate hand stroking is more affected by the context means that the time intervals of these key pairs have a flexible nature. The existence of this flexibility is quite obvious, since practically no factor restrains these key pairs, and the two strokes are quite independent of each other.

We may view the outcome here from the point of typing rhythm. All indications we have are in support of a view that such a levelling process is inherent in good typing behavior. In other words, there is a clear tendency to work towards a constant rhythm. It is hard to evaluate this effect quantitively, but we believe this plays an important role in the whole typing process.

Since this levelling must result from some mental scheduling procedure, it is likely that the more skilled a typist becomes, the more she will work towards rhythmical typing. This would mask the inherent weakness of the keyboard, as sugar coating covers up the bitterness of tablets. Therefore, the results of a superficial analysis of the performance on the results of a given keyboard is not directly usable to predict the expected performance on an entirely new keyboard.

6. Typing Errors

Errors occur quite frequently in typing, as was the case with our experiment. Here, we will attempt an analysis of the nature of common errors. The error statistics we obtained are given in tables (6-1) and (6-2).

Typing is a complex process involving many levels of human intellect and motion, and errors may occur in any one of these levels in various forms. For example, if the typist learns a word in a misspelled form, she will make constant errors with this word without even noticing them. But these errors, which result from visual or intellectual reasons, are not the kind we are interested in here. We shall investigate those that occur in conjunction with the mechanical motions of hands. These errors may occur either because the motion itself is inherently prone to errors, or because the typist has a particular deficiency for that motion. An example for the latter case is seen in our subject who has troubles with the word "little", typing it as "litle", "liitle", "littl", "litl", et cetra.

Generally, the pattern of errors depends on individual typists (much more than the distribution of typing speed does) and since we had only one subject in the experiment, the findings given below must not be thought of as a general result, though it should reveal at least a part of the truth. An additional limitation is that the subject was not accustomed to the keyboard used in the experiment. The effects of such factors as the reactive force of the keys against fingers, or the arrangement of special characters, may not be ignored.

Table (6-1): Errors in the Main Set.

Total	897 instances (602 distinct)
Omission	65.2%
Insertion	4.7%
Replacement	2.8%
Interchange	2.2%
Chatter	22.5% (Overlapped)
Other errors	17.6%

Table (6-2): Distribution of Omission Errors. (The middle key of the sequence is skipped.)

Text sequence		
L-R-L	7.4%	...10.0%
R-L-R	2.6%	
L-L-R	4.3%	... 9.1%
R-R-L	4.8%	
L-R-R	10.5%	...40.7%
R-L-L	30.2%	
L-L-L	6.9%	... 9.8%
R-R-R	2.9%	

Here, we will not look into errors with shift keys, although shift key errors form a category of their own. They are likely to occur in an interrupted state of mind, that is, when the mind is conscious of the typing behavior. The mistouching of either the shift or the character key that occur here is of a different quality from other simple mistouching, and these errors are not a good example of a deficiency in continuous reflexive motion. One typical example is that the typist went on typing a few lines without noticing that the shift key was locked.

The types of errors that occur within the main set are fairly limited. They are categorized as follows.

1) Omission: Errors that skip characters of the text. This is the most common type of error that is made by a well trained typist, since her touch is lighter than that of the less trained. They will be occasionally too light to go over the threshold of the key. These errors are found more frequently in faster sequences.
2) Insertion: Error that inserts extra characters that are not in the text.
3) Replacement: Error that hits an irrelevant key in place of a proper one. The most likely key to be mishit is the key adjacent to the proper one.
4) Interchanging: Error that hits a key pair in the reverse order. This appears to be a result of the peculiarity of individual typists.
5) Chattering: Error that a certain key is doubly typed. This error is characteristic of some electric typewriters. It often occurs together with the omission of the next character, which indicates that it occurs when the second key is hit while the first is still being depressed. The chattering itself may be due to too sensitively made keys, or to the trembling of fingers, or both.

The occurrences of errors are not evenly distributed, but are clustered. This implies that errors are in part due to some mental and physical state of the typist, especially the fatigue. At the same time, we see that a same error is repeatedly made, which means that the errors are not entirely due to carelessness, or statistical freaks. Errors are made more frequently by the left hand, although it may not be correct to infer this to be an indication of the inferiority of the left hand, since the total number of strokes typed by the left is also greater.

In the data, we see that more than 60% of the errors are omission errors. Further inspection shows that about 40% of the letter skipping takes place where the text goes either L-R-R-, or R-L-L-, where the second stroke in the sequence is the skipped key. From The previously obtained results, we know that alternate hand pairs can be stroked faster than same hand pairs, so we may infer that, because of the levelling effect, the typist would unconsciously try to speed up the same hand pair and such psychological stress would result in the skipping of the first key of the pair. Errors are made also where the sequence turns from an alternate hand mode into a same hand mode, which should accompany a similar psychological stress. The results obtained here are consistent with the observations in the preceding sections.

Errors tend to occur more frequently with words which are less familiar to the typist. A typical example is seen in the word "magnet" and their derivatives. The keying sequence of this word itself does not contain highly awkward sequences. Nevertheless, there are a large number of errors associated with them, so words which are unfamiliar to the typist must be more prone to errors. This aspect cannot be inferred from our discussion concerning the abstract natures of motions, so that it should be explained through a depth analysis of the particular motions associated with the word, in terms of psychological hesitation, analogy to familiar and similar words, lack of pattern practice for the entire word, etc.

7. Further Discussions

Briefly summarizing the observed results, we find that most of the conjectures stated about the dexterity of hand and finger motion is true for individual key pairs. However, the effect of these factors are not as pronounced as we first anticipated in the data, and taken as a whole, the data seemed to be quite dispersed. We attribute this to the effect of the context key pairs that work on them, and surmise that to think of a keying sequence merely as a juxtaposition of individual key pairs would not be sufficient, even at the physical level.

At the mental level, it is well known that typing is not a collection of individual letter typing but a typing of a longer pattern as a unit. A typist takes commonly used syllables (e.g. "-tion", "-ing", "-tive", etc.), words, or even phrases as a unit of recognition, not individual key pairs or characters. In the recognition, the text is segmented according to whether or not the typist has the knowledge of a particular chunk. This should be very closely related to the reading process in general. In typing, the term "knowledge" does not mean only that the typist understands the particular word, but also that she has a *canalization*, or a chunking ability, in her mind that translates the word into a sequence of keying motions. If the typist does not "know" the word, then it must be interpreted by syllables or maybe characters. Better defined canalization exists for frequently used words, hence for frequently used key pairs.

What we find in the results of our experiment is that this canalization exists not only in the mental aspect of typing, but also in actual physical motions of hands and fingers in typing. As a result, if a keying sequence contains a larger proportion of key pairs which are harder to execute, then even easier key pairs are slowed down in spite of the potential speed-up due to learning, and the overall typing speed settles down at a value which is below the attainable level as an aggregate of individual key pair performances. This is perhaps the main reason for the discrepancy between the actual reported performance figures on Dvorak keyboard, and the figures predicted for it by various authors based on the performance on QWERTY keyboard.

8. An Evaluation of the QWERTY Keyboard

What we have been observing in the preceding sections may be directly related to the evaluation of the effectiveness of the QWERTY keyboard.

Through the tallying of the text, we have the distribution of keystrokes on QWERTY as in table (8-1). The figures tell us that the left hand is overloaded, there are too many strokes typed on the upper row, the fingers are loaded poorly in relation to their dexterity, etc., all of which show the weakness of the QWERTY keyboard. Furthermore, the rate of awkward sequences is strikingly high; Of all the key pairs in the text, 9.6% are hurdles and 8.2% are reaches.

These results in themselves indicate the deficiency of the QWERTY keyboard, but these are not the crucial points. From the measurements made by others in the past, we have been told that for all these deficiencies, the QWERTY keyboard is no worse than by 20% in typing speed than by DSK. Some reported that the difference between DSK and QWERTY

Table (8-1): Stroke Distributions.

Hand Distribution (Shift key not counted.)		
Left	48.0%	
Right	35.9%	
Space bar	16.1%	
Row Distribution (Space bar excluded.)		
Top	0.1%	
Upper	51.5%	
Home	31.8%	
Bottom	17.6%	
Finger Distribution (per hand)		
	Left	Right
Index	37.2%	45.3%
Middle	34.8%	21.4%
Ring	14.0%	27.6%
Little	14.1%	5.7%

predicted through the analysis of QWERTY data is within only a few percents. Why can the difference be estimated so small? We think that this is due to the levelling effect, in which an expert executes hand motions through optimal paths. Supposedly slower stroking sequences will be pulled to be faster (and possibly become more prone to errors), and yet the faster ones might be made slower. The difficulty that is inherent in the keying sequence of the text on QWERTY, with all the awkward sequences and incessant wasted motions, is transformed into the tension of the hands of the typist in order to compensate for it, in an effect to type as rhythmically as possible. In this way, the resulting speed may not be affected as much as should be expected from the difficulty of individual strokes. Thus, when used to predict performance on DSK, such data will not give us a good estimate. The existence of unpreferred keying sequences affects the local performance of keying. In addition, continuous such effort on QWERTY certainly causes the fatigue of the typist, and it might even become hazardous to her health.

Based on these observations, we must reject the popularly stated notion that the QWERTY keyboard is a fully satifactory arrangement for English texts for most purposes.

9. Concluding Remarks

Many of the results we obtained confirm formerly stated claims on a basis of experimental results. The experimental proofs for the fact that the context of the text directly affects the production of the typing should be of value, for two reasons. One is that it shows that typing is a highly mental process, as well as a physical one of moving hands and fingers. Two, and what we wish to emphasize, is that this effect works in the direction of relaxing the tension that might occur in the typing process, so if we look at the typing behavior superficially, we might arrive at wrong conclusions about hand dexterity and the effectiveness of keyboards. Reports which support the efficacy of the QWERTY keyboard[8,9] appear to be making this error.

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