# United States Patent [19]

**Einbinder**

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[54] **INPUT KEYBOARDS**


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[51] **Int. Cl.**$^2$ .................................................. **B41J 5/10**
[58] **Field of Search** .................... 197/9, 98, 99, 100



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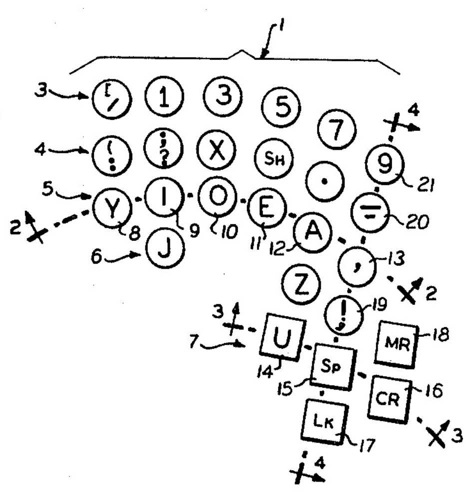
[57] **ABSTRACT**

Input keyboards are disclosed for typewriters, computer terminals, and other devices processing alphanumeric information that maximize entry rates and stroking accuracy, and minimize finger motions and the time needed to master the keyboard. A general method is also disclosed of designing such keyboards for any alphabetic language. The invention places the space key and four common vowels directly under the fingers of the left hand, and five common consonants directly under the fingers of the right hand. Two-finger chord strokes generate common two-character sequences belonging to the same hand. The keyboards are split into rotated halves containing curved key rows and slanted key tops of variable height to follow the architecture of the hand. The invention includes keyboards for English, German, French, Italian, Spanish, and Portuguese.

**17 Claims, 9 Drawing Figures**

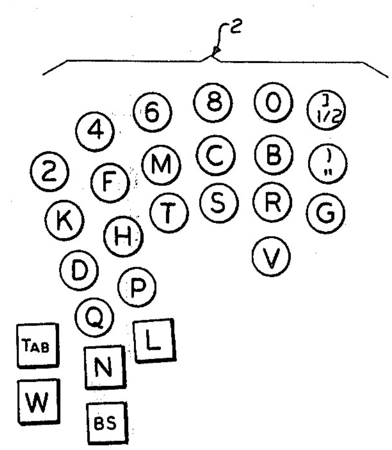


FIG. 1.
ENGLISH

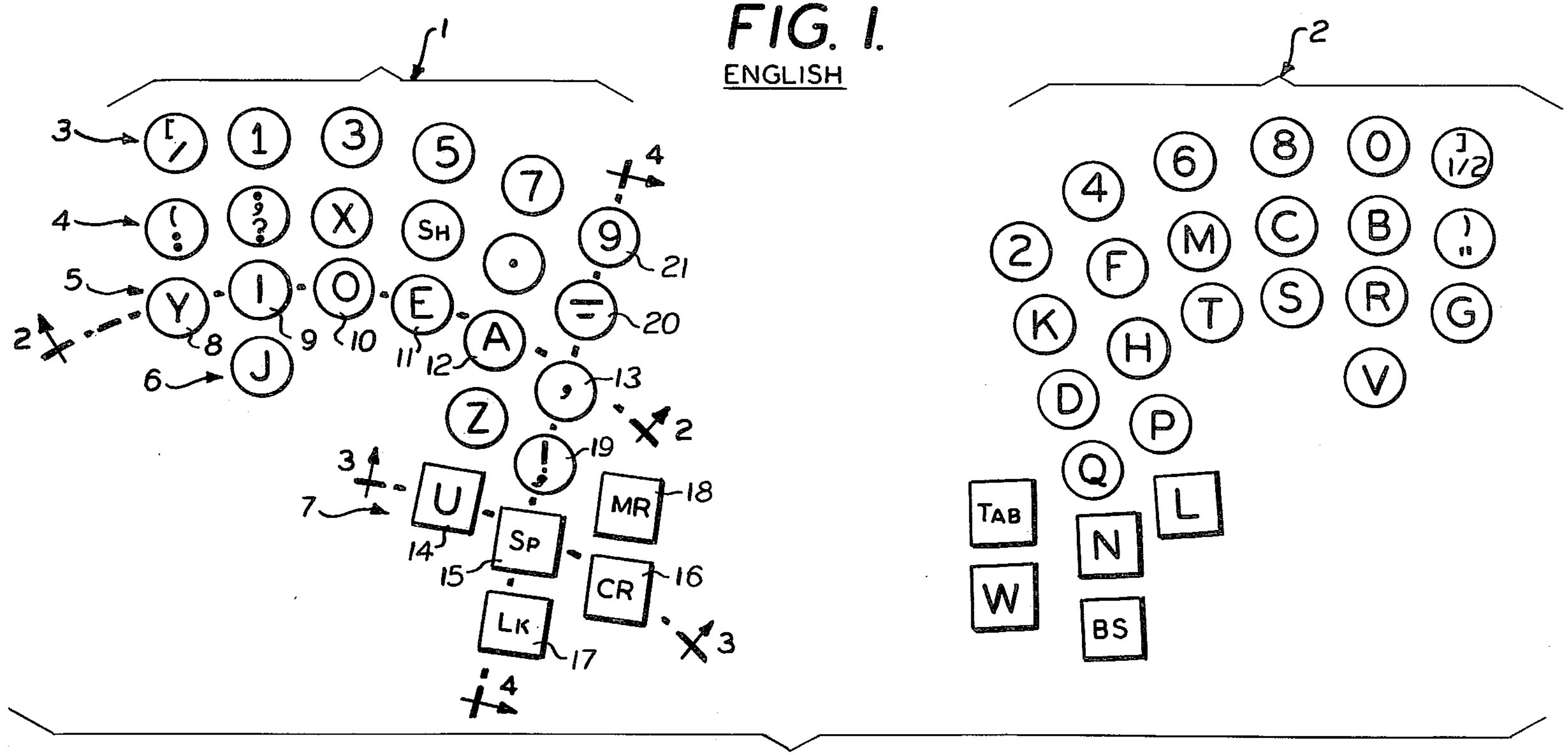



FIG. 2.

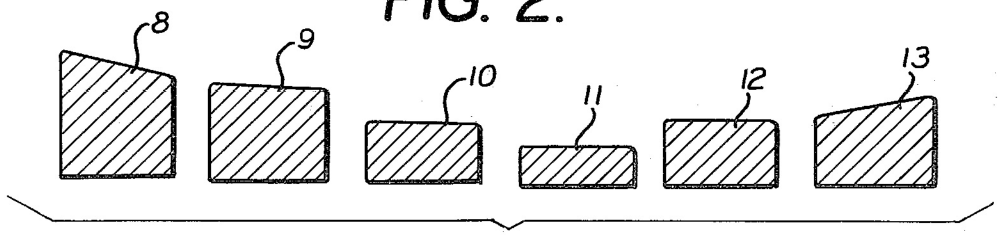



FIG. 3.

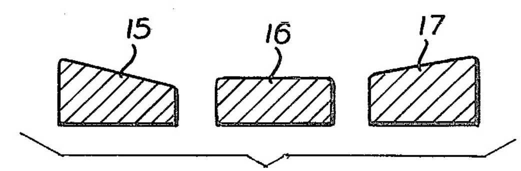


FIG. 4.

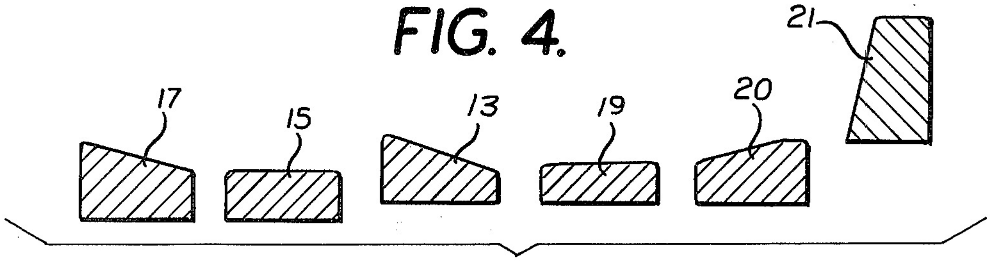



FIG. 5.

ITALIAN

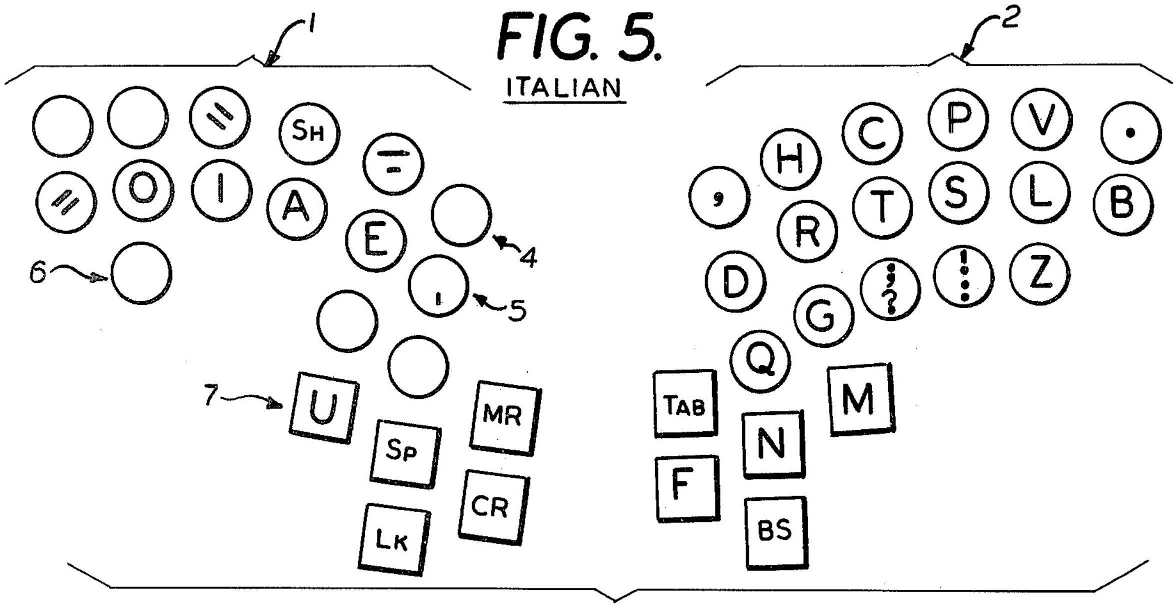



FIG. 6.

PORTUGUESE

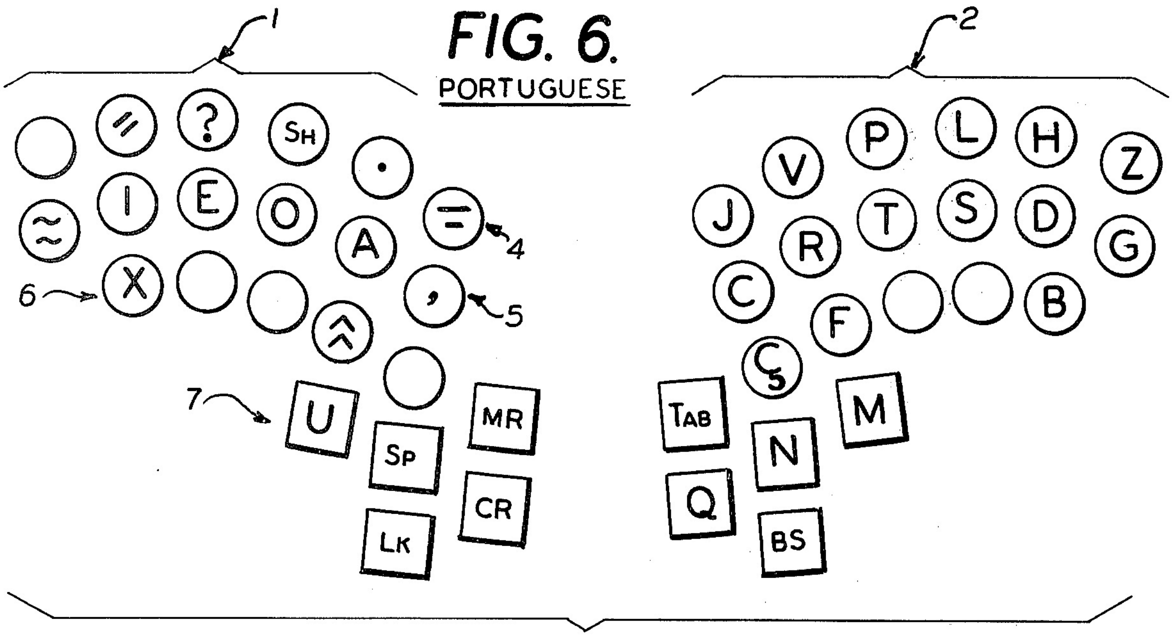


FIG. 7.
SPANISH

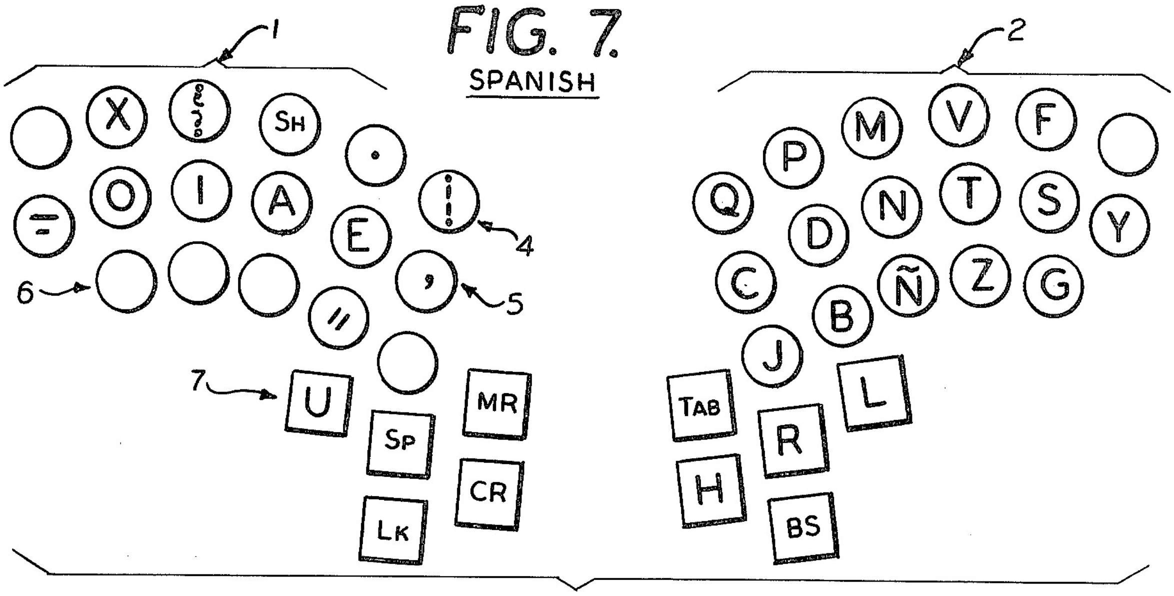


FIG. 8.
FRENCH

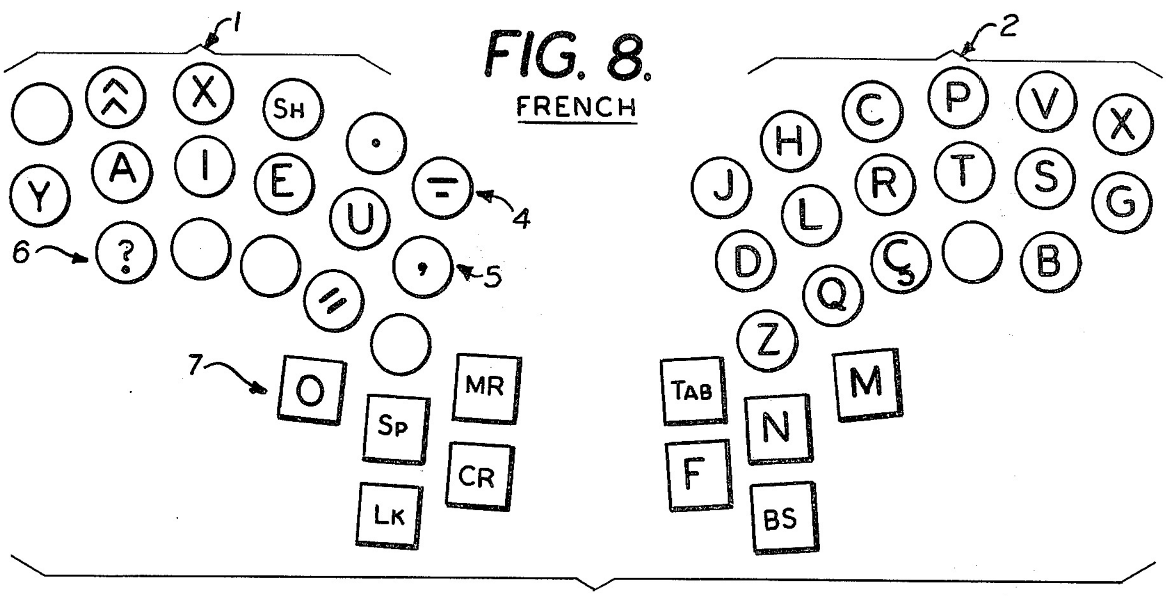
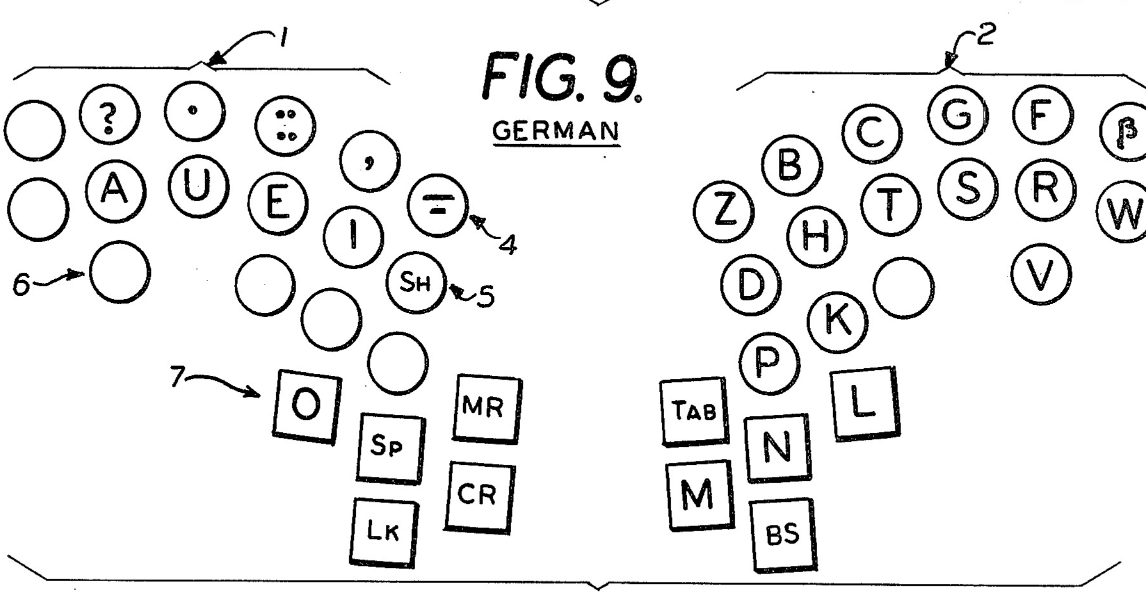


FIG. 9.
GERMAN



# INPUT KEYBOARDS

## FIELD OF THE INVENTION

This invention relates to input keyboards for typewriters, computer terminals, and other devices processing alphanumeric information, and methods of designing optimum keyboards in any alphabetic language. An input keyboard may be defined as an array of keys operated by the fingers of both hands to transfer graphic characters and control instructions to a machine. The keyboard thus serves as an interface between a human operator and a machine handling alphanumeric symbols. The output may include, but is not limited to, visible characters on paper (typewriters), characters on a flourescent screen (cathode ray tubes), holes in paper tapes or cards (tape perforators, card punches), or changes in the magnetization of tapes or disks (computer input stations).

## DESCRIPTION OF THE PRIOR ART

The keyboard is an interface between man and the machines producing this written language. During recent decades, major advances have been made in the means of generating this written language. Electric typewriters have replaced manual machines, Electronic word processing devices are displacing electric typewriters, and computer controlled photocomposers are surplanting linotype machines. Yet despite these technical advances, an ancient, inefficient keyboard devised a hundred years ago has remained undisturbed.

Operators throughout the world use essentially the same keyboard, even though they input material in a variety of alphabets whose letters have different frequencies and combine in different ways. Consequently operators are forced to struggle with a keyboard whose arrangement of letters and controls disregards the properties of the language they are processing and the geometry of the human hand.

This incompatibility is a product of the history of the universal keyboard, which is a direct descendant of the manual typewriter invented in America a century ago. As early as 1878, the Remington typewriter reproduced the arrangement of letters and punctuation marks appearing on the contemporary keyboard. This American keyboard was adopted as an international standard in 1888, and was swiftly accepted in European countries with only minor modifications to meet the needs of different languages. Thus on the German keyboard, the *ö* and *ä* appear at the right-hand end of the home row, and the *y* and *z* are interchanged because the *y* is extremely rare in German. Similar changes have been made in other European languages, but for practical purposes, their keyboards are essentially equivalent. Such uniformity might be helpful if individuals processed information in many languages, but this is rarely the case. Instead operators are burdened with a keyboard that ignores the statistical characteristics of their native language.

The linotype keyboard used in printing is even more inefficient. It consists of ninety keys arranged in six rows. Lower-case letters are assigned to the left hand, and upper-case letters to the right hand. Because of mechanical limitations in early linotype machines, the commonest letters are alloted to the little and second fingers of the left hand. The *a*, *e*, *i*, *o*, *n* and *t* are assigned to the little finger, and the *u*, *d*, *h*, *l*, *r*, and *s* to the second finger. This arrangement prevents rapid input because of the long vertical reaches to strike keys in different rows and the large number of successive strokes made by the little and second fingers of the left hand. This clumsy layout is still retained in contemporary linotype machines, even though the mechanical restrictions that originally dictated this choice no longer apply.

The defects of the universal typewriter keyboard emerged fifty years ago as the proficiency of typists improved and touch typing became widespread. Today these deficiencies are even clearer. Fingers dart over the standard keyboard executing complex stroking patterns. The middle row is not a true home row. In English, 52% of the letter strokes occur on the top letter row, 33% on the middle row, and 15% on the bottom letter row.

The universal keyboard is a left-hand arrangement in a righthanded world. The left hand executes more difficult strokes than the agile right hand. Approximately 2,700 common words may be keyed by the left hand, but only 300 by the right hand. Half the successive letters in representative prose passages lie on the same hand, which is the same fraction that would occur if the keys were randomly distributed. Some of these sequences require three or four strokes by the same hand, which are slower and more difficult to complete than strokes on alternate hands. Many common digraphs must be keyed by the same finger. Striking successive keys with the same finger is very slow because fingers cannot prepare for a second stroke while the first one is being made. Examples include combinations involving the *r* and *t*, the *c* and *e*, the *u* and *n*, and the *l* and *o*.

About 30% of the motions on the universal keyboard are hard to execute. They include awkward reaches from the home row, successive strokes by the same finger, and hurdles across the home row to operate keys on the top and bottom letter rows. Because of the absence of a true home row, mastering the standard keyboard demands considerable dexterity, since the hands are in constant motion reaching for keys on different rows.

The location of letters and controls ignores the varying strength of individual fingers. Shift keys are operated by the little finger, which requires considerable effort on manual machines. Mechanical necessity a century ago fixed the geometric location of keys, which has remained unchanged. The straight key rows do not follow the contours of the hand; the staggered vertical key array in adjacent rows are awkward to strike. Fingers must traverse oblique paths to reach keys on different rows, and the weak little fingers must operate the shift keys at the corners of the keyboard. Such awkward movements produce muscular fatigue, since operators may complete 50,000 to 80,000 key strokes during an average working day.

Mastering the standard keyboard requires extensive practice. Modest facility generally takes 50 to 100 hours. Resulting speeds usually do not exceed three to five strokes a second even after lengthy training. For every hour of practice, input rates typically increase by only one stroke a minute, due to the complexity of required finger movements. Error rates are essentially independent of stroking skill, ranging from one to four errors a minute. Errors are increased by the poor location of keys and the inefficient arrangement of letters and controls. Errors are distributed over so many possibilities, they cannot be effectively reduced by practicing on a specialized vocabulary. Research studies show that special exercises are ineffectual in improving keyboard facility. All finger motions must be practiced at the same time using ordinary English to supply letter combinations in accordance with their natural frequency.

The standard keyboard has been repeatedly criticized in Europe because of its American origin and neglect of Continental linguistic differences. European languages cannot be processed efficiently on this keyboard. In German, 46% of the successive letter strokes are made by the same hand, which is close to the values for a random arrangement of letters. The left hand executes 58% of the letter strokes—the more agile right hand 42%. The eight keys directly under the fingers account for only 24% of the letter strokes on the German keyboard. The middle row is not a true home row, since 49% of the strokes are made on the top letter row, 32% on the middle row, and 19% on the bottom row.

For several generations, inventors have sought to correct the deficiencies of the universal keyboard. They have proposed setting common letters directly under the eight fingers of both hands to reduce stroking movements and make the middle row a true home row. They have advocated curved key rows to fit the hand, and raised key tops to compensate for differences in finger length. They have suggested splitting the keyboard in two, and moving the shift keys to the center of the keyboard to be operated by the thumb or fourth fingers. These geometric innovations, however, have been frustrated by the poor arrangement of letters and controls which masks any improvements due to spacial changes.

The standard keyboard has remained unchanged, despite its defects. Manufacturers would not make typewriters with a new keyboard unless a market existed for them. Businessmen would not order such machines unless employees could operated them. Schools would not teach a new keyboard unless it was used by the business world. The ensuing impass has blocked progress and left the universal keyboard firmly entrenched.

A new keyboard will not be adopted unless it yield substantial economic benefits. Initially the most promising applications will be in fields where input is a major expense. An example is computerized typesetting where keyboarding now represents approximately 80% of the cost. Another field is data processing, where data input accounts for about 40% of the expense. Considerable savings should be possible because operators currently execute an averagee of 12,000 strokes an hour (three characters a second) during a working day.

To win commercial acceptance, a new keyboard must lead to faster entry (50 to 100%) and lower error rates. To overcome entrenched resistance, employees must be able to acquire stroking facility in a short time (**100** hours or less), and secure greater speed and accuracy after brief training than is possible on the standard keyboard after extended practice.

Rapid entry depends on the skill and training of operators, as well as the layout and arrangement of the keys. Efficient training is important because of the initial absence of skilled operators and the reluctance of experienced personnel to exchange a keyboard they know for one that is unfamiliar. Individuals must be taught who are already proficient on the standard keyboard, as well as those who have little or no experience. Instruction must lead quickly to stroking facility and



confirm the ease of mastering a new key arrangement. Swift progress during early training is necessary to win acceptance and encourage executives to bear the cost and inconvenience of teaching employees to operate new equipment.

Previous inventors have slighted the problem of teaching a new key configuration. They have presented calculations of stroking efficiency, but ignored the fact that substantial differences between competing designs do not appear until considerable entry speeds are reached. At low and moderate rates (below five characters a second) the presence of awkward movements is masked because keys are stroked one at a time. At higher rates, clumsy movements impair performance by hindering chain stroking in which one finger prepares for a stroke while another one is being made. This gap in entry rates from one character to five characters a second is precisely the difference that separates a novice from a skilled operator on the standard keyboard. Unless this gap can be bridged quickly and economically, the utility of a new keyboard will be nullified by the expense and difficulty of reaching skills where its superiority becomes evident.

Earlier inventors have failed to develop effective instruction materials that lead to fast input and early chain stroking. The history of the Dovrak-Dealey keyboard is revealing in this respect. Ever since its invention in 1932, the Dvorak keyboard has been advocated as a replacement for the universal keyboard. Its advantages have been described in newspapers, magazines, and technical journals, but despite this publicity, the keyboard has not gained a foothold in the business world.

A major reason is the absence of learning materials that utilize the simplified motions occurring on the Dvorak keyboard. Training exercises have mimicked instruction methods employed on the standard keyboard by concentrating on individual letters rather than stroking sequences. Consequently most operators who learn the Dvorak keyboard do not acquire chain stroking, and are unable to demonstrate its superiority under actual working conditions.

Sound keyboard design and effective instruction must be based on the statistical properties of the language and the kinesthetic capacity of the brain and fingers. Setting common letters directly under the fingers of each hand improves stroking efficiency. Additional principles are required, however, to fix the arrangement of letters because of the large number of possible permutations.

Eight letters can be arranged in $8!=40,320$ ways. If the most frequent vowel and the most frequent consonant are placed under the third finger of each hand, $6!=720$ distinct keyboards can be formed with the remaining six letters. Finally, if four common vowels are set under the fingers of one hand, and four common consonants under the fingers of the other hand, $4!\times4!=576$ arrangements are possible.

In view of this host of alternatives, when even a small number of keys is involved, further principles must be employed to reduce the number of possibilities and restrict competing designs to a few keyboards possessing comparable efficiencies. Alternate designs must be evaluated numerically, since direct experimental tests are not feasible. Such tests are ruled out because of the time and expense of training operators, the large number of subjects required for statistically valid results, and the contamination of test scores by variations in the skill, instruction, and practice materials used by operators on different keyboards.

Empirical studies reveal that the fastest strokes are made on alternate hands when one finger prepares to make a stroke while another finger is striking a key. The time taken to complete successive strokes increases with their motor difficulty. These strokes are in order of difficulty: strokes on home keys by alternate hands; strokes on different rows by alternate hands; strokes on home keys by the same hand; strokes on a home key and a key in another row by different fingers of the same hand; strokes outside the home keys by different fingers of the same hand; and strokes on different keys by the same finger.

For skilled operators, the slowest strokes take three times longer than the fastest ones. Therefore for rapid entry, a majority of successive strokes should be made by alternate hands on home keys, and a minimum by the same finger on different keys.

Dvořak and Dealey applied these findings to develop a simplified keyboard for the English language based on kinesthetic and linguistic principles (U.S. Pat. No. 2,048,248). They recognized that twoletter combinations must be considered as well as single letter frequencies because the time required for a particular stroke depends on its immediate predecessor. Dvorak and Dealey employed a table of English digraph frequencies to determine the letter arrangement on their simplified keyboard. They set vowels on the home row of the left hand—and high-frequency consonants on the home row of the right hand. Punctuation marks and rare consonants were assigned to the left hand—and the remaining consonants to the right hand.

This choice remedies many of the faults of the standard keyboard. Separating vowels and consonants increases alternate hand motions. Placing consonants under the right hand insures that a majority of two-letter digraphs are stroked by the agile right hand. Dvorak and Dealey demonstrated the superiority of their keyboard by calculating the relative frequency of different strokes and comparing them with those on the standard keyboard which overworks some fingers and demands many difficult stroking motions. Dvorak and Dealey catalogued these difficult motions and proved numerically that operating the universal keyboard is a taxing kinesthetic task.

Although the Dvorak keyboard marked a major advance, it has significant limitations. It retains the clumsy geometric configuration of the standard keyboard with its crooked reaches to adjacent rows—and leaves shift keys at the corners to be stroked by the little finger. Operating the Dvorak keyboard requires only nine fingers—eight fingers to input the letters, and a thumb to strike the space bar. The placement of letters is not optimum. The *p* appears on the vowel side of the keyboard, which leads to many one-hand motions. The *u* lies under the fourth finger of the left hand, rather than the *i* which occurs twice as often.

On the theoretical side, the Dvorak-Dealey table of digraphs is incomplete. It omits double letters which account for 1.7% of the letters and spaces in English. It also ignores the space, although the space is the commonest character in English, accounting for one out of every six characters. (The same mistake was made by Roy Griffin who proposed a "Minimotion" keyboard based on an elaborate statistical study of digraph frequencies that erroneously disregarded the space separating words.) Space-letter digraphs are important because a majority of words begin and end with a consonant on the right side of the keyboard. Therefore using the right thumb to stroke the space bar on the Dvorak keyboard, following the practice on the standard keyboard, leads to many onehand strokes.

## SUMMARY OF THE INVENTION

Accordingly it is a principal object of this invention to supply a general-method of designing keyboards in any alphabetic language that maximizes the speed and accuracy with which a human operator can transfer alphanumeric information to a machine.

Another object of this invention is to present the complete optimum keyboard for the English language, and optimum keyboards containing the most important letters and symbols for German, French, Italian, Spanish, and Portuguese.

Another object of this invention is to provide a keyboard utilizes all ten fingers to enter alphabetic material and control instructions. Another objective is to furnish a keyboard that lightens the stroking load on the fingers and increases the separation of vowels and consonants by assigning character and control keys to both thumbs.

Another object is to base keyboard design on the neural capacity of the brain and fingers, and the statistical properties of alphabetic texts. Another object is to minimize stroking errors and finger movements by allocating characters in accordance with their statistical frequency. Another aim is to furnish an optimum letter arrangement for any alphabetic language by means of a frequency count of 100,00 characters without a detailed knowledge of the language.

Another aim is to reduce keyboarding to a set of simple, independent finger motions. Another object is to maximize successive strokes on alternate hands by assigning consonants to the right hand—and vowels, punctuation marks, diacritical marks, and rare consonants to the left hand. Another object is to minimize successive strokes by the same finger, and essentially eliminate triple strokes by the same hand by separating vowels and consonants in the keyboard. Another objective is to utilize the greater dexterity of the right hand in processing two-letter combinations by assigning consonants to the right hand. Another goal is to provide a keyboard that reduces substitution errors by alloting characters of widely different frequencies to the same finger. Another goal is to make touch typing automatic by placing ten common characters directly under the fingers. A further goal is to increase the speed of numerical input by assigning odd digits to the left hand, and even digits to the right hand.

An object of this invention is to supply a keyboard that reducess fatigue by fixing horizontal and vertical key positions to conform with the architecture of the hand. Another object is to decrease stroking errors by dividing the keyboard into two separate sections. A further object is to lessen muscular tension by rotating each section of the keyboard, so the forearm, wrist, and hand lie in a straight line from the shoulder. Another objective is to reduce digital strain by curving key rows to follow the geometry of the hand. Another objective is to equalize stroking motions by raising key tops to compensate for differences in finger length. Another goal is to to permit the home position to be located by touch by varying the height of home keys. Another goal is to ease stroking by inclining the thumb row from flexure to extension. A further goal is to simplify numerical input by means of vertically oriented stroking surfaces on the number row that can be operated by a horizontal motion of extended finger tips.

Another object of this invention is to provide a keyboard that generates common two-character combinations by simultaneously operating two home keys. Another object is to make these simultaneous chord strokes easy to execute by using key-pairs under adjacent fingers, or the thumb and another home key. Another goal is to furnish a keyboard that expedites learning these chords by making their output identical with the keys struck in a majority of cases. An additional goal is to utilize remaining chords to reduce movements from the home row and eliminate clumsy finger motions.

An object of this invention is to provide a keyboard which generates upper-case characters by means of a single shift key that acts on one character and automatically returns the system to lowercase operation. Another object is to replace multiple strokes after certain punctuation marks by a single stroke. Another object is to pass from one sentence to another by a single stroke, and from one paragraph to another by means of a single chord. Another objective is to eliminate carriage return strokes by automatically advancing the system to the next line when a space or hyphen key is operated within a given number of spaces from the end of a line.

Another objective is to reduce the number of keys on foreign language keyboards by employing a single dead key for individual diacritical marks.

Another aim of this invention is to provide a keyboard that enables stroking facility to be acquired rapidly by practicing on a limited repertory of finger movements that occur frequently in natural texts. Another aim is to supply a keyboard that hastens chain stroking by allowing instruction to concentrate on alternate-hand strokes on home keys, and permits numerical input to be mastered by practicon digits arranged in alternate-hand sequences.

Another object of this invention is to decrease the training time of average operators and to increase their entry speed by simplifying keyboard motions. A final object is to provide keyboards that allow training methods developed for one language to be applied to other languages.

## KEYBOARD ARRANGEMENT

This invention describes a systematic method of designing optimum keyboards in any alphabetic language for typewriters, computer terminals, and other devices processing alphanumeric information. The design maximizes input rates and stroking accuracy, and minimizes finger motions and the time required to learn the keyboard. The invention assigns characters and controls to both thumbs, setting common characters directly under the fingers of both hands.

The space and vowel keys are alloted to the right hand, and consonants to the right hand. A majority of successive strokes are on alternate hands—a minimum on the same finger. Three out of four strokes occur on home keys directly under the fingers, permitting rapid acquisition of keyboard facility. The speed of chord stroking is combined with the ease of serial input by employing two-key chords to enter common two-character combinations on the same side of the keyboard. Double letters are generated by holding down the corresponding letter key.

Keys are spacially arranged to fit the hand. The keyboard is divided into the two separate halves. Each half is rotated about 15°, so the hand, wrist, and forearm lie in a straight line from the shoulders when fingers rest on the home keys. Key rows are curved to follow the shape of the hand. Key tops have variable heights to compensate for differences in finger length. Key tops outside the home row are tilted for easy stroking from the home position. The thumb row is inclined to follow the thumb from flexure to extension; its keys are recessed to prevent them from being struck accidently by the fourth finger. Stroking surfaces on the number row are vertically oriented, so they can be operated by a horizontal motion of extended finger tips.

Consonants are set on the right side of the keyboard. Vowels, punctuation marks, diacritical marks, and rare consonants are on the opposite side of the keyboard. The space key lies under the left four high frequency vowels directly under the remaining fingers of the left hand. Five high frequency consonants lie directly under the fingers of the right hand. In most European languages, these nine characters correspond to the commonest vowels and consonants in the language. The left thumb row is completed by another vowel and the carriage return key; and the right thumb row by two more consonants.

The four common vowels that lie directly under the fingers of the left hand are: *a*, *e*, *i*, and *o* in English, Italian, Spanish, and Portuguese. The five high frequency consonants that lie directly under the fingers of the right hand are: *n*, *r*, *s*, *t*, and *h* in English and German. The *u* replaces the *o* as one of the home vowels in German and French. The *l* replaces the *h* in French and Italian; and the *d* replaces the *h* in Spanish and Portuguese.

These letters are arranged on home keys so that common digraphs on the same hand may be stroked by adjacent fingers, or by the thumb and another finger. Operating these key-pairs simultaneously, plus the pair keyed by the little and fourth fingers furnishes sixteen chord, eight on each hand. These chords are used to enter leading digraphs, such as vowels and spaces at the beginning and end of words, plus common consonant combinations (such as th, st, and ng in English).

The number row is split into even and odd portions. Odd digits are assigned to the left hand—even ones to the right hand. Dead keys produce diacritical marks in foreign languages, but do not advance the system in the horizontal direction. A single shift generates upper-case characters. This key acts on only one character, automatically returning the system to lower-case operation. Striking the space and hyphen keys within a given number of spaces from the end of a line automatically advances the system to the next line.

The lower-case period generates the multiple characters needed to go from one sentence to another. Chord strokes produce the characters reequired to pass from one paragraph to another. Operating the lower-case comma, colon, or semi-colon keys automatically produces a space after each of these punctuation marks. Operating the uppercase period and comma key produces the period and comma appearing in decimals, numbers, and abbreviations.

For the English language, the location of letters and symbols on the keyboard is, going from the little to the fourth finger, as follows:

On the left hand: on the number row—(open bracket/slash), **1**, **3**, **5**, **7**, and **9**: on the top letter row—(open parenthesis/colon), (semi-colon/question mark), *x*, shift, period, and (underline/hyphen); on the home row—*y*, *i*, *o*, *e*, *a*, and comma; on the bottom letter row—*j*, *z*, and (exclamation point/apostrophe); on the thumb row—*u*, space, and carriage return, plus margin release and shift lock.

On the right hand: on the number row—(close brackets, onehalf), **0, 8, 6, 4, 2;** on the top letter row—(close parenthesis/double quotation marks), *b*, *c*, *m*, *f*, and *k;* on the home row—*g*, *r*, *s*, *t*, *h*, and *d;* on the bottom letter row—*v*, *p*, and *q;* and on the thumb row—*l*, *n*, and *w*, plus tab and back space.

Simultaneously operating two keys by the same hand generates the following output:

On the left hand: (space, *e*) produces *e* then space; (space, *i*) produces space then *i;* (space, *a*) produces space then *a;* (space, *o*) produces space then *o;* (*i*, *o*) produces io, (*e*, *a*) produces ea; (*e*, *o*) produces ou; (*i*, *a*) produces *y* then space; (shift, period) produces a period, carriage return, tab, and a shift; and (shift, question mark) produces a period, two carriage returns, and a shift.

On the right hand: (*t*, *h*) generates th; (*s*, *t*) generates st; (*r*, *s*) generates rs; (*r*, *h*) generates ch; (*n*, *t*) generates nt; (*n*, *s*) generates ns; (*n*, *h*) generates nd; and (*n*, *r*) generates ng.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is top view of the keyboard for the English language illustrating the location of letter and control keys, and the spacial division of the keyboard into two rotated halves containing curved key rows that follow the shape of the hand.

FIG. **2** is a cross-section through aa home row taken along the line **2—2** of FIG. **1** illustrating the variable heights of key tops in a given row, and the inclined key tops outside the home position.

FIG. **3** is a cross-section through a thumb row taken along the line **3—3** of FIG. **1** illustrating the inclined thumb key tops outside the home position.

FIG. **4** is a cross-section through a vertical set of keys at the inner boundary of the keyboard taken along the line **4—4** of FIG. **1** illustrating the recessed thumb keys, the inclined key tops outside the home position, and the vertically oriented key tops on the number row.

FIG. **5** is a top view of part of the keyboard illustrating the location of the most important letters and symbols for the Italian language.

FIG. **6** is a top view of part of the keyboard illustrating the location of the most important letters and symbols for the Portuguese language.

FIG. **7** is a top view of part of the keyboard illustrating the location of the most important letters and symbols for the Spanish language.

FIG. **8** is a top view of part of the keyboard illustrating the location of the most important letters and symbols for the French language.

FIG. **9** is a top view of part of the keyboard illustrating the location of the most important letters and symbols for the German language.

## DESCRIPTION OF THE PREFERRED EMBODIMENTS

### The Ten-Finger Keyboard

The optimum keyboards presented in this invention correct each of the shortcomings described above.

The keyboards of this invention are ten-finger keyboards which employ both thumbs as well as other fingers, and fully utilize the stroking capacity of the thumbs to enter letter and control instructions. Using both thumbs for input has many advantages. The thumbs are the strongest finger and possess the greatest freedom of movement. Thumb keys can be operated without disturbing other fingers. Successive or simultaneous strokes of a home thumb key and another home key by the same hand can be readily executed because of the way the thumb is joined to the hand.

Ten-finger keyboards have been introduced in the past in stenographic machines, telegraphic terminals, and chord typewriters. On stenographic machines, words are represented by an initial consonant cluster chorded by fingers of one hand, followed by a vowel cluster stroked by the thumbs, terminated by a second consonant cluster chorded by the fingers of the second hand.

The thumbs serve a different function in the present invention. The left thumb rests on the space key on the vowel side of the keyboard, flanked by a vowel on one side and a carriage return on the other. The right thumb rests on a common consonant on the opposite side of the keyboard, flanked by two less frequent consonants. Using the thumb to enter consonants permits more choice in arranging letters and improves the separation of vowels and consonants.

Distributing consonants on all five fingers is a marked asset because consonants outnumber vowels in nearly all alphabetic languages. English has six vowels and twenty consonants (five of which occur often). Comparable proportions occur in other European languages. Thumb input allows five high frequency consonants to be placed directly under the fingers. Setting common characters under each finger insures that most strokes will lie on home keys. In English and most European languages, the ten home-key characters account for roughly three out of four key strokes. Consequently the arrangement of letters on the home keys determines the basic layout of the keyboard.

Assigning characters to both thumbs allows letters to be distributed more efficiently. It lightens the kinesthetic load on other fingers, and enables controls (shift, tab, carriage return) to be placed in the center of the keyboard. Alloting letters to all ten fingers reduces stroking errors and accelerates learning by differentiating the muscular sensations and spacial positions associated with particular letters. Thumb keys also eliminate the need for keys on the lower letter row assigned to the second and third finger which are difficult to stroke.

Determining the best arrangement of characters and controls on a keyboard involves awkward compromises. For maximum performance, a number of simultaneous conditions must be satisfied that may be incompatible. The larger the number of alternatives, the smaller the compromise required to meet these conditions. Assigning letters to the thumb permits the keyboard to be tailored to the language being processed. Using all ten fingers for input multiplies the number of ways letters can be alloted to individual fingers. On the consonant side of the keyboard, the five home keys can be arranged in $5!=120$ different ways. On a conventional keyboard with four home keys, only $4!=24$ permutations are possible.

Thumb entry leads to greater freedom in choosing letters outside the home position because they can be placed on an additional finger. Since two letters may be assigned to $n$ fingers in $n(n-1)$ ways, a pair of consonants may be distributed in twenty ways on five fingers, but in only twelve ways on four fingers. This increase simplifies stroking motions and aids accurate entry of common digraphs because letters may be arranged so these digraphs can be stroked by adjacent fingers, or by the thumb and another finger. Seven such strokes exist on each hand on the ten-finger keyboard (three on adjacent keys, and four involving the thumb), but only three are possible on the standard keyboard.

## Kinesthetic Constraints

A fundamental analysis of keyboard design must consider two factors: the capacity of the brain to direct the fingers to strike an ordered sequence of keys, and the statistical properties of the language being processed. The first factor belongs to the field of human physiology. It controls the rate at which operators learn a new keyboard and the stroking rates they achieve after extended practice. The second factor belongs to the area of linguistics. It determines the optimum arrangement of characters on the keyboard.

Since a keyboard is an interface between man and the machine, the physiological capacity of the operator must be considered in setting realistic performance goals and developing effective methods of learning a new key configuration. Earlier inventors have erroneously assumed that an efficient key arrangement would automatically solve the problems of keyboard learning and eliminate the kinesthetic constraints imposed by the brain and fingers. But this is not the case.

Entry rates on the standard keyboard fall far below physiological limits. A fast typist may stroke 5 to 9 keys a second (corresponding to 50 to 90 six-character words a minute) on a typewriter whose mechanical speed may vary from 10 to 18 characters a second. Measured tapping rates, however, are much greater. For a 15 second test, maximum tapping frequencies have been reported as high as 48 a second for the little finger of the left hand, and 70 taps a second for the fourth finger of the right hand. These frequencies mount in moving across the hand from the little to the fourth finger.

The time taken to execute a stroke increases with its difficulty and complexity; measured response times lengthen as visual stimuli and motor responses diverge. Thus skilled operators on stenographic machines execute only three chord strokes a second, because they must depress several keys simultaneously, and the output generated does not bear a simple relation to the keys depressed. (This slow input is offset by extensive use of stenographic abbreviations.)

Keyboarding involves conversion of visual stimuli into finger motions through the mediating action of the brain. This task is not performed efficiently because mental associations between alphabetic stimuli and key strokes are hard to establish. The brain has a limited memory for motor movements and attaches a single conditioned reflex to each visual cue. As a result, mastering a new letter arrangement effectively destroys the kinesthetic associations previously established for an earlier arrangement.

Learning behavior illustrates the difficulty of connecting alphabetic stimuli with stroking responses. Students must give keyboarding their undivided attention, expending considerable mental effort to "tell" the brain which key to strike. Deciding on the appropriate finger motion is initially slow and laborious. Novices may take a second to strike each key. Often they attempt to make learning easier by siliently vocalizing letters they are trying to strike, striving to reinforce the weak connection between visual and stroking responses by auditory associations.

Lengthy practice is required before one finger can prepare for a stroke while another one is being made (chain stroking). At first the brain processes only on character at a time. Gradually more information is handled as entry speeds increase. Observation reveals that operators adjust their intake to their stroking speed —reading "one second ahead" to supply the brain with the number of characters they can stroke in one second.

The contrast between the arduous acquisition of keyboarding and man's gift for speech is striking. People can learn to speak several languages and easily switch from one to another, employing a vocabulary of thousands of words. But they can learn only a small repertory of finger motions. Although individuals may speak several languages, they can operate by touch only a single keyboard using the Roman alphabet because their motor response to a given alphabetic stimulus is fixed. This limitation is due to the organization of the brain, rather than differences in the muscular capability of the fingers, the larynx and vocal chords.

The disparity between human speech and keyboard ability may be explained by man's early history. Natural selection favored the development of a "speech-making" brain, because speech was a powerful asset in a hostile environment. Primitive man used his hands to hunt, gather food, build shelter, and fashion tools and weapons. But these manual tasks are far removed from the motions and associations required for keyboarding. Therefore man's brain is not suited for transforming visual cues into finger strokes, since this activity has no counterpart in his early history.

The brain's kinesthetic inefficiency has important consequences for keyboard design. A successful configuration must employ a small vocabulary of finger motions that should be easy to execute. Motor choices alloted to any finger should be limited, and a majority of successive strokes occur on alternate hands to exploit the cerebral independence of opposite-hand motions. Finger strokes on each side of the keyboard are controlled by different regions of the brain; left-hand strokes by the right hemisphere of the brain; and right-hand strokes by the left hemisphere of the brain. This provides a neurological basis for chain stroking where the fingers of opposite hands move independently. Keyboard learning is facilitated when characters assigned to each hand possess common linguistic features that enable them to be swiftly identified with the appropriate stroking hand (governed by the opposite hemisphere of the brain). This is true for the optimum keyboards of this invention which allot consonant keys to the right hand, and space and vowel keys to the left—and even and odd digits to opposite hands.

Keyboards that assign many alternatives to individual fingers place a heavy processing load on the brain. Learning times for such keyboards are excessive—their input rates slow. An example is Ayres' word writing machine (U.S. Pat. No. 3,225,883) which has a separate set of consonants and vowel keys for letters at the beginning and end of words. Another example is Seibel's communication device (U.S. Pat. No. 3,022,878) which uses transducers connected to the joints of each finger to translate digital orientations into chord strokes. More than a thousand different chords can be produced on this device by the fingers of a single hand. Experiments show, however, that motor learning is not completed on this device, even after 75,000 trials, because of the great number of chords available. Consequently its great information handling capacity is dissipated by the long time needed to learn these chords, and the high error rates associated with their large number.

The ten-finger keyboards of this invention reduce the kinesthetic alternatives alloted to each finger by assigning characters to all ten fingers. These keyboards lighten the processing load on the brain by setting common characters directly under the fingers, so that three out of four strokes may be executed by simply depressing keys under the fingers. In addition, they aid learning by separating vowels and consonants, so that seven out of ten strokes lie on alternate hands. Finally, these keyboards permit common one-hand digraphs to be stroked easily by alloting two-charater combinations to adjacent fingers, or the thumb and another finger.

## KEYBOARD GEOMETRY

Engineering the keyboard to fit the hand simplifies the motor movements required and reduces the neural instructions that must be transmitted from the brain to the fingers. Making vertical and horizontal key positions conform with the human hand eliminates clumsy stroking motions, resulting in lower error rates and less muscular fatigue.

The ten-finger keyboard is split into two symmetric halves; one for each hand, as shown in FIG. **1:1, 2.** The half operated by the right hand is rotated clockwise about 15°; the half operated by the left hand is rotated counter-clockwise about 15°—so that when the fingers of each hand rest on their respective home keys **9, 10, 11, 12, 15,** the forearm, wrist and hand extending from the shoulder lie on a straight line on each side of the keyboard. This arrangement eliminates sources of muscular tension and increases the spacial segregation of vowel and consonant strokes.

Key rows are set in curved convex arcs to follow the natural curvature of the hand—FIG. **1: 3, 4, 5, 6.** Keys above and below home row **5** are placed so that when fingers resting on home keys straightened, they pass over the center of the inclined keys on the upper letter row **4** and strike the center of keys of the vertically oriented keys on the number row **3.** When fingers on home keys are bent, they pass over the center of the inclined keys on the lower letter row **6.** This makes it easier for fingers initially on the home row to strike keys on adjacent rows.

Dividing the keyboard into two separate sections produces an irregular contour that furnishes useful visual cues in learning key locations at the extremities of the keyboard. It also prevents the fourth finger of one hand from erroneously striking keys in the center of the keyboard assigned to the opposite hand, which occurs on solid key arrays.

Straightening the reaches from the home keys provides more assurance in operating keys in other rows because fingers must be merely bent or straightened to reach these keys. The curved key array also simplifies operating keys at the extremities of the keyboard, since these keys are symmetrically placed. Finally, straightening the paths to adjacent keys permits true typing on the number row. This is virtually impossible on the standard keyboard because the irregular relation between keys on the home and number rows forces even skilled typists to rely on visual cues to enter digits accurately.

To facilitate numerical input, stroking surfaces on the number row are vertically oriented, as illustrated in FIG. **4.** These keys can be struck by a horizontal motion of extended finger tips from the home position. Accuracy is enhanced because number keys may be stroked by straightening the fingers, which is easier kinesthetically than extending a finger horizontally and then striking down on a horizontal key top. The vertically oriented surfaces on the number row slope away from the home row, as illustrated in **21** of FIG. **4,** to reduce the likelihood that a finger nail rather a finger tip will strike the vertical key. Tilting these key surfaces away from the home row also improves sight lines to the number row, allowing mixed visual and tactile cues to be used in entering numerical data.

Key heights on the ten-finger keyboard vary to compensate for differences in finger length, as illustrated in FIG. **2.** Keys operated by the little finger **8, 9** are tallest, followed by the fourth finger **12, 13,** then by the second finger **14,** and finally by the third finger **15.**

Varying the heights of individual keys increases stroking speed and comfort, particularly for the little finger. Equalizing motor movements associated with different fingers, permits faster entry of chords involving adjacent fingers, especially for the little finger. A vertically contoured keyboard enables hands to be placed on home keys using tactile cues without viewing the keyboard. Such cues are absent on the standard keyboard where all keys have the same height. (On the standard keyboard, the right hand is often misplaced side of the home row.)

Thumb input permits keys to be spread over a greater area—supplying spacial associations that supplement muscular sensations in differentiating vowel and consonant strokes. The thumb keys **14, 15, 16, 17, 18,** indicated by squares in FIG. **1,** protrude from a recessed plane. Their tops lie deeper than key tops operated by the fourth finger, as illustrated in FIG. **4.** This variation in height prevents the thumb or fourth finger from mistakenly striking keys on adjacent rows.

The thumb row **7** is inclined at a oblique angle to follow the movement of the thumb from extension to flexure. This permits more precise striking of the three thumb keys **14, 15, 16** on the thumb row because these keys lie directly under the thumb when it is bent from flexure to extension.

On the ten-finger keyboard, hands remain poised over the home row while keys on other rows are operated. Key strokes to adjacent rows are simplified by sloping key tops outside the home position as illustrated in FIG. **4.** Key tops on the lower letter row **6** and the upper letter row **4** slope toward the home row **5** which rests in a slight trough. Key tops are inclined so that key edges nearest the home position lie deeper than key edges farthest from the home position. Keys at the end of the home row **8, 13** slope toward nieghboring home keys, facilitating return of the little and fourth fingers to their home positions, as shown in FIG. **2.** Thumb key tops outside the home position **14, 16, 17, 18** slope toward the flat home thumb key **15** on which the thumb normally rests, as illustrated in FIG. **3.** The edge of thumb keys nearest the home key lie deeper than the edge farthest from the home thumb key, expediting return of the thumb to its home position.

Thumb keys replace keys on the lower letter row alloted to the second and third finger on the standard keyboard that are difficult to stroke. (These keys may be retained to accomodate diacritical marks and additional letters in foreigh languages, or the 96 characters of the ASCII character set used in computer input and optical character recognition devices.) Eliminating keys operated by the second and third fingers on the lower letter row reduces the number of strokes to this row and increases the geometrical isolation of keys at the lower extremities of the keyboard. This in turn reduces substitution errors caused when adjacent fingers mistakenly strike neighboring letters on solid key arrays. A similar increase in accuracy occurs on the thumb row whose keys are isolated from the rest of the keyboard.

## Linguistic Statistics

Stroking motions depend on the character sequences in the language and the distribution of letters on the keyboard. Before describing a systematic procedure of arranging letters that minimizes finger motion in any alphabetic language that can be keyboarded, it is useful to examine the general characteristics of natural languages (as distinguished from artifical codes or cryptographic ciphers).

Natural texts are ordered strings of symbols carrying information. The number of letters employed must be large enough to reproduce the vocabulary and sounds of the language, yet small enough to limit the number of rare or redundant characters. In most European languages, this requires 24 to 32 letters, which can be readily keyboarded. But the number may vary from 21 letters in Finnish to 38 in Czech. Extensive alphabets are a handicap in the modern world because they make keyboarding difficult. Therefore governments have sought to prune unwieldy alphabets and eliminate redundant characters. (After the Russian Revolution, the Soviets cut the Russian Cyrillic alphabet from 36 to 32 letters.) Serious efforts have also been made to simplify non-alphabetic languages, such as Japanese and Chinese, to permit them to be written (and keyboarded) more easily.

Since written languages are vehicles of communication, they possess statistical similarities as information-carrying alphabetic codes. Individual letters appear with varying frequencies, because it is a fundamental principle of information theory that a random sequence of characters cannot contain any information. (A random sequence may be defined as one in which all one-character, two-character, . . . n-character sequences are equally probable.)

When characters are ranked in the order of their occurrence, their relative frequency in various languages is quite similar. This uniformity increases for languages possessing a common alphabetic and linguistic ancestry. The Romance and Germanic languages are important examples; they use the Roman alphabet and share a common Indo-European origin.

About a third of the letters in these languages occur often. The remainder appear with decreasing frequency, concluding with a set that rarely occur. In English, the space and four commonest vowels (*a*, *e*, *i*, and *o*) account for 42% of the characters. Another 29% are represented by the five commonest consonants (*n*, *r*, *s*, *t*, and *h*). In contrast, the five rarest consonants (*j*, *k*, *q*, *x*, and *z*) account for less than 1% of the text.

Leading characters in European languages possess a similar frequency distribution. Table 1 records the individual frequencies of the space and five commonest vowels in English, German, French, Italian, Spanish, and Portuguese. Table 2 lists the individual frequencies of the six commonest consonants in these languages. Table 3 records the cumulative frequencies of the space and four commonest vowels, the five commonest consonants, and the ten commonest characters in these languages. (These tables and later ones disregard the numbers and punctuation marks that make up about 3% of ordinary texts, as well as diacritical marks.)

Although vowels appear more often in Romance languages (French, Italian, Spanish, and Portuguese) than in Germanic ones (English, German, Dutch, and Swedish), the cumulative frequency distribution of ranked characters is similar in major European languages. According to Table 3, the ten commonest characters (which usually lie directly under the fingers on optimum keyboards) account for about three out of four characters. This uniformity exists despite differences in the size of the alphabet in these languages.

This regularity persists even for languages represented by syllabic rather than alphabetic symbols. Thus the 48 kana, which transcribe Japanese phonetically, possess a ranked frequency distribution that is comparable to the ranked letter distribution in European languages (when a correction is made for the larger number of kana).

Characters carry more information when they appear with varying frequency. Since written languages have evolved as efficient means of communication, their word lengths and letter frequencies are distributed to facilitate transmission of information. The space is almost always the most frequent character because the commonest words are invariably short monosyllables that are easy to speak and write. (The 50 commonest words in English, which account for 40% of the words in typical texts, are all monosyllables.)

Although the cumulative frequency distribution of ranked characters is substantially the same in major European languages, the rank of individual letters vary from language to language. Table 4 lists the maximum and minimum frequencies of individual letters (ignoring spaces) in nine languages. The table reveals the substantial spread between these maximum and minimum frequencies. The *e* amounts to 19.3% of the letters in Dutch, but only 10.2% in Swedish. The *o* represents 11.5% of the letters in Portuguese, but only 2.1% in Dutch; the *d* is 6.4% in Danish, but 3.4% in French. Likewise, the *i* accounts for 11.3% in Italian, but only 5.7% in Swedish; the *h* occupies 5.6% of the text in English, but only 0.7% in Spanish.

In addition to these wide differences, some letters are common in certain languages, but virtually absent in others. The *y* appears more than once in every hundred letters in English and Spanish, but is extremely rare in German, Italian, and Portuguese. The *w* occurs an average of once in every seventy letters in English and German, but less than once per thousand in French, Spanish, and Italian. LIkewise, the *q* appears about once in every hundred letters in French and Spanish, but hardly ever occurs in English, German, or Swedish.

Because of these wide variations, the letter arrangement on optimum keyboards will be diffeent in each language. This conclusion is reinforced because vowel-vowel and consonant-consonant digraphs must be considered, as well as individual letter frequencies in minimizing stroking motions. These two-letter combinations yield several hundred additional frequencies which, when added to individual letter frequencies, furnish each language with a unique statistical profile.

This profile assigns unique frequencies to one and two-letter combinations. When these frequencies are ranked in numerical order, an underlying similarity emerges connecting various European languages. This similarity insures that the distribution of finger motions on the optimum keyboards of this invention will resemble each other, even though specific strokes produce different letters. In particular, the proportion of alternate-hand and home-key strokes will exhibit similarities in Various European languages. As a result, principles of keyboard design developed for one language may be applied to other languages—and numerical methods of analyzing finger motions may be carried over from one language to another.

Digraph frequencies determine the optimum letter arrangement. These frequencies, however, cannot be derived from single-character values because successive letters are not statistically independent. The probability of a pair of letters appearing depends on their order. (In English, the digraphs th, nd, and ea are far more probable than the reverse digraphs ht, dn, and ae.) Phonetic constraints favor alternating vowels and consonants, rather than successive consonants or vowels. Linguistic rules also bar certain combinations as admissible words. (In English, a *u* always follows a *q*, but a *q* never follows a *b*, *f*, or *t*.)

According to Shannon's pioneering study of the information content of written English [Bell System Technical Journal, vol. 27 (1948), p. 379], letter sequences in natural texts may be assumed to be generated stochastically (by chance). As a first approximation character sequences may be assumed to be governed by a Markov process in which the likelihood of a character appearing is given by the transition probability linking a character and its immediate predecessor. (These transition probabilities may be obtained from a table of digraph frequencies by dividing individual digraph frequencies by the number of digraphs in which the second character appears.)

The Markov hypothesis is a useful first approximateion because it excludes forbidden letter sequences and takes account of correlations between adjacent characters. It assumes, however, that the probability of letters occurring depends on only the preceding character. This hypothesis is violated in most languages for sequences involving three successive vowels (vowel trigraphs), or three successive consonants (consonant trigraphs), because the probability of these sequences is sharply reduced by the predominant alteration of vowel and consonant phonemes (sounds). Since phonemes are usually represented by one or two letters (such as *n*, th, ch, and ng in English), most consonant and vowel trigraphs are formed by a union of monosyllabic roots containing initial and terminal consonants, or vowels (as in inch, control, and impress).

The relative absence of vowel and consonant trigraphs is important in keyboard design. Placing vowels and consonants on opposite sides of the keyboard curbs triple strokes by the same hand by reducing the number of one-hand trigraphs. For English and the Romance languages, a majority of these trigraphs may be processed by a chord and a home-key stroke, so that only chordless trigraphs present difficulties. But these trigraphs are so rare, they can be ignored.

The practical absence of trigraphs requiring three strokes by the same hand, which might be predicted on linguistic grounds, has been verified for the English language by a computer count of one million words. This count proves that grouping vowels and consonants on opposite sides of the keyboard greatly simplifies stroking motions by reducing the number of one-hand trigraphs to one-eighth their value on the standard keyboard. Similar conclusions hold for the Romance languages. More consonant trigraphs appear in Germanic languages (German, Dutch, and Swedish) because of the ease with which they compound monosyllables to form polysyllabic words. However, a judicious arrangement of letters combined with chording can diminish the effect these trigraphs on overall processing rates.

Due to the relative absence of one-hand trigraphs, only one-hand digraphs need by considered in developing optimum keyboards. The distribution of these digraphs can be determined by counting the frequency with which pairs of characters appear in representative texts. Single letter frequencies may be obtained by summing the digraphs in which a specific letter appears in either an initial or final position.

Only letters and spaced need by included in the diagraph table. Digits, which account of for about 1% of the characters in ordinary texts, may be disregarded because they appear as independent linguistic entities, separated by spaces from other words, and are customarily assigned a separate row or bank of keys. Puntuation marks may also be omitted because they are governed by editorial convention, rather than intrinsic properties of the language. Thus the amount of punctuation has dropped sharply in English during the last sixty years without a corresponding change in the language itself. Since punctuation marks are attached to the ends of words (period, comma, hyphen), or at well-defined points within words, (the apostrophe), their intersection with other letters may be ascertained from letter and space digraph frequencies.

The location of the period and comma keys on the vowel side of the keyboard is significant because they appear nearly once in every hundred characters. Optimum placement requires a knowledge of the frequency with which these punctuation marks are preceded by specific vowels. This information, however, may be determined with sufficient accuracy from vowel-space digraphs.

Digraph frequencies are obtained by tabulating successive characters in a sample text. If these values are to apply to the language in general, the sample must be representative of the entire language and include enough characters so that statistical flucatuations may be neglected. If the sample is biased, observed frequencies will depart systematically from population values, since common words will occur too often (or too rarely). For instance, samples drawn from works of fiction, or business and personal correspondence, contain a much higher proportion of personal pronouns than extracts from scientific papers or government reports. Similarly, extracts from learned and technical writing include longer words and fewer spaces than samples from colloquial sources. if telegraphic texts are used, which is the practice in cryptography, the letter *h* will appear only 60% as often as in ordinary English prose, because of the absence of such common words as the, that, this, he, and his from telegrams.

Drawing extracts from a variety of genres decreases the likelihood of sampling errors due to an eccentric distribution of words. Sampling errors will effect only a limited number of digraphs; they will not influence keyboard design if they consist of alternating vowel-consonant pairs, since design depends on one-hand digraphs (consonant-consonant, vowel-vowel pairs). Consequently the letter arrangement on the optimum keyboards of this invention are not sensitive to sampling variations.

In determining digraph frequencies, the sample must be large enough so that statistical fluctuations due to the finite sample size may be neglected. Since digraphs are sampled from a multinomial distribution, the standard deviation of individual digraph frequencies will vary as the square root of their observed frequency—and the standard deviation of their probability will vary inversely with the square root of their observed frequency.

Digraph frequencies of interest range from several per cent down to one per thousand (the lower limit is somewhat arbitrary, since it represents the frequency below which specific stroking motions can be ignored). Common digraphs containing characters directly under the fingers, which determine the arrangement of home keys, average a fraction of 1%. For keyboard design, the relative rank of differeent stroking motions is required rather than their absolute values. Therefore a sample of 100,000 characters is sufficient to reduce statistical fluctations to acceptable levels. With this sample size, an observed digraph frequency of 400 has a standard deviation of 20, and the standard deviation of its probability is 5%.

A much larger sample is necessary to evaluate the importance of specific trigraphs because they occur with lower frequency. Since significant one-hand trigraphs appear from three to five times less frequently than corresponding digraphs, a sample of one to two million characters is needed to obtain reliable data on particular trigraphs. The tabulation of these trigraphs is simplified, since only combinations occurring entirely on the consonant or vowel side of the keyboard need be included. A much smaller sample is sufficient, however, to determine the cumulative fraction of one-hand digraphs or trigraphs in a given language.

## Digraph Table for the English Language

Because of its importance, a large sample has been used in compiling the digraph table for the English language (Table 5). The sample consists of a one million words containing 5.7 million characters (letters and spaces). The sample is composed of 500 selections of contemporary American English, each approximately 2,000 words long. These extracts have been taken from newspapers, magazines, biographies, bellelettres, learned and scientific writing, in addition to various forms of fiction (to simulate letter frequencies occurring in personal and business correspondence). Strictly speaking the digraph table refers to American English. However, it can be used for British English because differences due to British usage and spelling are negligible as far as keyboard design is concerned.

In Table 5, the space is represented by a hyphen. The recorded values are based on a sample of 5.7 million characters, normalized to 100,000 characters and rounded off to the nearest integer. (Rounding errors explain why row and column totals differ from each



other, and from the totals at the bottom of the table recording the frequency of individual characters.

## Keyboard Design

This invention describes a systematic procedure of designing an optimum keyboard in any alphabetic language that can be keyboarded. The method employs kinesthetic principles and a statistical count of two-character combinations to determine a letter arrangement that minimizes finger movement and reduces input to a small set of independent stroking motions. The procedure is described in detail for the English language to indicate how the method is applied to other languages, which will be discussed later. Definite reasons govern the location of every character on the keyboard. For English, each character is in a different position than on the standard keyboard.

Grouping vowels and consonants on opposite sides of the keyboard is a fundamental element of this invention. Vowels, (diacritical marks), rare consonants, and puntautaion marks are set on the left side of the keyboard; the remaining consonants on the right side. Four high frequency vowels and the space key are placed directly under the fingers of the left hand—and five high frequency consonants directly under the fingers of the right hand. For most European languages, the home-key characters are the ten commonest characters in the language, accounting for about three out of four of the letters and spaces in representative texts. These high frequency characters lead to automatic touch typing, since most strokes are made on home keys hidden from view.

Vowels and consonants may be identified from a digraph table by the way they combine with other letters. Vowels consist of a small group of letters that combine often with a larger set of letters (consonants), but rarely with themselves. Similarly, consonants appear often with nearly all vowels, but with only a limited set of consonants.

The procedure of grouping letters on opposite sides of the keyboard may can be applied in languages, such as Hebrew and Arabic, that omit vowels from their written language. In this case, consonants may be divided into two groups, composed of letters that tend not to combine with each other. Segregating these letters on the keyboard minimizes the number of one-hand strokes, and succeeds in any language whose characters transmit information, since its character sequences must exhibit statistical regularities.

Letters are arranged on optimum keyboards according to their frequency. Common letters appear on home keys directly under the fingers; letters with middle frequencies on adjacent keys; and rare characters at the extremities of the keyboard. When two keys outside the home position are assigned to the same finger, the character occurring more often is set closer to the home position.

Distributing characters according to their frequency minimizes substitution errors produced when the same finger operates keys of comparable frequency. An example occurs on the standard keyboard, where the common consonants *r* and *t*, lie side by side. These letters are often mistakenly substituted for each other because they they are both stroked by the fourth finger of the left hand. Such sustitution errors are reduced on the optimum keyboards of this invention because characters are alloted to the same finger differ sharply in frequency.

Common letters are assigned to the home keys. The next group are on the thumb and home rows in the center of the keyboard, alloted to the thumb and fourth finger, respectively, because these keys are easiest to stroke outside the home position. To minimize successive strikes by the same finger, characters assigned to the same finger are chosen so they rarely form digraphs together. Letters are arranged on different rows so that important digraphs can be readily executed. To lighten the stroking load on the little finger, low frequency letters are placed on keys operated by the little finger. When a diacritical mark appears with several letters in foreign languages, each diacritical mark is alloted to an individual dead key that generates the diacritical mark, but does not advance the system in the horizontal direction. This reduces the number of separate keys that must be learned.

Characters on home keys are distributed so that major digraphs may be stroked by adjacent fingers, or by the thumb and another finger. These letters are arranged so common digraphs may be stroked serially on the same row in motions from the little finger to the fourth finger, or a thumb stroke followed by another finger stroke. Such movements suit the architecture of the hand, and are easier to complete the sequences in the opposite direction.

Since common letters lie under the fingers, home keys on the ten-finger keyboard in English, German, French, Italian, and Portuguese are essentially determined by the vowel and consonant frequencies given in Table 1 and 2. In English, Italian, Spanish, and Portuguese, the four vowels lying under the fingers of the left hand are *a*, *e*, *i*, and *o*. In German and French, the *u* replaces the *o* as one of the vowels under the fingers of the left hand. In English and German, the five consonants under the right hand are *n*, *r*, *s*, *t*, and *h*. In French and Italian, the *l replaces the h;* and in Spanish and Portuguese, the *d* replaces the *h* as a home key.

The consonant with the largest number of substantial one-hand digraphs is assigned to the thumb key, since the thumb has the greatest kinesthetic independence. The choice of vowels and consonants on home keys is straightforward when the four commonest vowels and the five commonest consonants appear much more often than other vowels and consonants, respectively. When other letters have comparable frequencies, the letters selected for the home keys possess the largest number of significant one-hand digraphs, particularly with other home keys to permit rapid entry of common digraphs. This is the reason that the *t* is chosen as a home-key in Spanish rather the the *l* or *c*, and the *t* as a home character in Portuguese instead of the *m*, although the *l*, *c*, and *m* occur with a similar or greater frequency.

In general, the number of letters with a similar frequency is limited because languages are information-bearing alphabetic codes whose letters appear with varying frequency. The choice of home-key letters if evident in English because the four commonest vowels and the five commonest consonants appear much more often than othe vowels and consonants. The *i* (6.0%) occurs more frequently than the *u* (2.2%); the *h* (4.8%), more often than either the *l* (3.4%) or the *d* (3.3%). This choice of home keys is confirmed gy comparing one-hand digraphs. The *i* has two significant digraphs, space-(1187) and io (447); but the *u* has only one, ou (634), which may be produced by a chord. Likewise the *h* has three substantial digraphs, th (2337), ch (378), and wh (258); but the *l* and *d* appear in one each: ld (202) and nd (851), and nd may be replaced by a chord. (In this paragraph and subsequent paragraphs, percentages in parentheses refer to the frequencies of individual letters including the space. (The numbers in parentheses following digraphs record their occurrence per 100,000 letters and spaces, as given in Table 5.

Since *n* appears as the initial letter in the common digraphs: nc (244), nd (851), ng (664), ns (294) and nt (618); the *n* is set under the right thumb. The location of the space key under the opposite thumb is confirmed by the substantial digraphs: *e*-space (3524), space-a (2010), space-i (1187), and space-o (1248).

The commonest consonant, *t* (7.6% ), is placed under the third finger. It is flanked by the *h* and *s* to permit speedy entry of th (2337) and st (720). The *h* is assigned to the fourth finger because the *h* rarely combines with the other consonants in the center of the keyboard. Finally, the *r* is alloted to the little finger for quick input of rs (270) by the little and second fingers.

On the vowel side of the keyboard, the commonest vowel, *e* (10.3%), is set under the third finger. The *a* is under the fourth finger for swift stroking of ea (474); and the *i* and *o* lie side by side for easy input of io (447).

To lighten the stroking load on the little finger, the *y* is placed at the outer end of the vowel home row because it is the final letter in 70% of the words in which it appears. The *g* is set at the outer end of the consonant home row because it is preceded by the *n* in 40% of the words in which it occurs. Chording the digraph *y-space and ng sharply reduces movement of the little finger to strike tye y* or *g*.

Since letters are arranged to minimize successive strokes by the same finger, the *i* is assigned to the little finger on the home row, since it rarely combines with the *y*. This in turn fixes the *o* under the second finger. The *u* is set on the thumb row. Alloting the fifth vowel to the thumb facilitates learning by identifying a different vowel with each finger. In addition, it reduces substitution errors produced when two common vowels are assigned to the fourth finger in the center of the keyboard.

Since the letter *u* rarely begins or ends a word in English, successive strikes by the thumb are limited. The carriage return is on the thumb row next to the space key because it replaces the the space at the end of each line. Since the *u* (2.2%) occurs more often than the carriage return (1.7%), the *u* is assigned to the flexed thumb key in the center of the keyboard, and the carriage return to the extended thumb key at the outer end of the thumb row, because the flexed key is easier to operate than the extended thumb key.

The high frequency consonants *d* and *l* are set on the end of the home row and the thumb row, respectively, because the *d* rarely combines with the *h*, and the *l* seldom joins with the *n*. Medium frequency consonants are placed on the top letter row opperated by the second, third, and fourth fingers. The *c* (2.6%), *m* (2.1%), and the *f* (1.9%) are alloted to the second, third, and fourth fingers, respectively, because they rarely combine with the *s*, *t*, and *h* operated by the same fingers. This arrangement permits easy entry of the digraphs ct (237) and fr (137).

Other letters are distributed in a similar fashion. The *p* (1.7%) is alloted to the fourth finger on the lower letter row because it rarely combines with *h*, *d*, or *f*.

This location also enables the digraphs pr (268), pl (166), and mp (136) to be stroked readily. Similarly, the *w* (1.5%) is set on the thumb row because it seldom appears with the *l* or the *n*. This allows the digraph wh (258) to be easily stroked by the thumb and fourth finger. The *b* (1.3%) and the *v* (0.8%) are assigned to the little finger because they occur infrequently. The *b* is on the upper letter row so the digraph bl (155) can be executed by straightening the little finger and flexing the thumb.

The principles used in arranging letters on the consonant side of the keyboard can be applied to rare consonants on the opposite side of the keyboard. Since the digraph ex (122) occurs in four out of five words in which the *x* appears, the *x* is assigned to the second finger on the upper letter row to expedite stroking this digraph. Likewise, since ju (43) appears in two out five words in which the *j* appears, the *j* is set on the lower letter row, so ju can be stroked by moving the little finger and the thumb toward each other. The question mark is assigned to the little finger because it appears infrequently, and the *z* is set on the lower letter row next to the vowels to assist in stroking combinations involving the *z* and vowels.

Major punctuation marks (period, comma, hyphen) are alloted to the strong fourth finger in the center of the keyboard. This choice minimizes successive strikes by the fourth finger because these punctuation marks rarely follow the letter *a*. It also permits the common sequences *e*-comma and *e*-period to be executed swiftly by the third and fourth fingers. Since one word in six ends in *e*, the shift key is set on the upper letter row over the *e* to prevent the third finger from having to make two successive strokes when keys are individually operated. This isolation succeeds because a space or a tab precedes a shift. Furthermore, when keys are serially operated, the sequences (punctuation, space) and (hyphen, carriage return) may be executed by a simple kinesthetic motion.

Substitution errors are minimized by setting rare characters at the extremities of the keyboard. The *k* (0.5%) is at the edge of the keyboard operated by the fourth finger of the right hand, next to the *f* (1.9%), which appears four times more often. Similar adjacent key-pairs containing characters of widely differing frequency include on the left hand: (one, slash), (question mark, colon), and (period, hyphen)—and on the right hand: (*p*, *q*), (*b*, double quotation mark), and (zero, one-half).

The principle of maximizing alternate hand movements restricts the location of certain keys. The tab is assigned to the right thumb because it usually follows a carriage return stroked by the opposite thumb. The *q* (0.1%) is set on the consonant side of the keyboard because it is followed by a *u*. The apostrophe is set with the vowels, since it appears either between consonants in contractions (as in it's, don't, and can't), or before the *s* in possessives. Double quotation marks are grouped with consonants because they generaly precede a shift stroke in opening a quotation—and normally follow a comma, period, or question mark in closing a quotation.

The space and back space keys are on opposite thumbs to facilitate moving the system to and fro horizontally. Placing controls with related functions, or symbols resembling each other, on opposite hands eliminates the motor confusion that occurs when they are alloted to the same finger, or the same hand. For this reason, open and close brackets are set at the opposite ends of the number row, and open and close parentheses at the opposite ends of top letter row to symbolically enclose their respective key rows.

Since parentheses are often used in contemporary English prose to mark off parenthetical clauses and sentences, these symbols are placed on the top letter row. This row contains twelve keys, instead of the eleven on the standard keyboard. The introduction of an additional key on the top letter row allows the colon to be given a lowercase position under one parenthesis—and the double quotation marks to be set under the other parenthesis. The semi-colon is assigned to an upper-case position over the question mark because it is much rarer than the colon. Likewise, the exclamation point is set in the upper-case position over the apostrophe because it is very rare.

Associative learning is accelerated by arranging characters so they can be readily associated with specific hands. This technique, which has been employed on the letter rows by dividing the keyboard into vowel and consonant sides, is utilized on the number row by allotting odd digits to the left hand, and even ones to the right hand. These numbers are arranged in serial order from left to right: 1, 3, 5, 7, 9 . . . 2, 4, 6, 8, 0. The zero is next to the eight, so fingers operating the zero and one keys will be responsible for a single digit each. This is desirable because the zero and one appear twice as often as other digits. The slash and the one-half keys are at the outer ends of the number row because both symbols usually appear with other digits. The one-half key is placed next to the zero key, instead of the one key to prevent the one and the one-half keys from being erronesouly interchanged.

Splitting the number row into even and odd sequences permits digits to be entered by a two-step associative process. The first step identifies a digit with a specific hand—the second step, with a specific finger. Since even and odd is a concept that has been instilled in individuals since childhood, students can associate the left hand with odd digits more readily than with the numbers one through five, and even digits more readily with the right hand than with the numbers six through zero. Retaining the serial order of digits on each side of the number row makes it easier to learn the location of specific digits—and leads to faster entry of numerical data when mixed visual and touch typing is employed by reducing the visual field that must be scanned.

The "pipe-organ" method may be fruitfully employed for numerical input. In this method, the hands are shifted from the home row to the upper letter row, so the fingers are in contact with the vertically oriented number keys, which serve as a new set of home keys. Numerical data can be inputed accurately by moving the hands from one row to another, like a musician playing an organ, instead of reaching for number keys across the top letter row while holding hands stationary on the home row. The hands can be shifted quickly back and forth because the keys in different rows lie in straight lines above each other and the contoured keyboard supplies helpful tactile cues to guide the hands to home position.

Since control keys are located in the center of the keyboard, fingers can remain in contact with the vertically oriented number keys, while thumbs operate the space, tab, and carriage return keys. The period needed to enter decimals, and dollars and cents can be stroked easily because the period and shift keys are on the top letter row. The pipe-organ method is particularly effective in processing numerical data in tabular form because fingers can rest against the number row while thumbs rest on the tab and carriage return keys. This is impossible on the standard keyboard where the right hand must be removed from the number row to strike the period and carriage return keys. Furthermore shifting the hands between the home row and number row is awkward on the standard keyboard because the keys are staggered on different rows, and there is no tactile cues to guide the fingers to the home position.

## The Programmed Keyboard

The keyboards of this invention are designed to permit the use of programmed instructions in response to single key or chord strokes when the keyboard is attached to sophisticated devices, such as electronic typewriters, word processing machines, CRT terminals, and computer input stations, whose electronic circuity can convert key strokes into a desired output. Such circuity simplifies the entry of alphabetic information by replacing repetitive sequences executed by human operators by machine instructions.

ON the programmed keyboards of this invention, a single stroke produces the characters needed to go from one sentence to another— and a single chord generates the strokes required to go from one paragraph to another. Common one-hand digraphs are produced by simultaneously striking pairs of home keys. Programming also eliminates the necessity of operating the carriage return at the end of each line.

Although most keyboards are controlled electrically or electronically, it is still usually necessary to hold down the shift key to input upper-case characters. This slow, time-consuming method of entering capitals is a legacy from the manual typewriter. Generating an upper-case character entrails two separate actions: shifting to the upper case—then releasing the shift to return the system to the lower case. Learning to enter capitals on the standard keyboard demands extensive practice because each capital must be associated with one of the two shift keys at the corners of the keyboard, which must be operated by an awkward motion of the little finger.

These obstacles are absent on the keyboards of this invention which use only one shift key (assigned to the third finger of the left hand, except for German). This shift key acts on a single character and automatically returns the system to lower-case operation after an upper-case character is produced. This allows the shift and upper-case character keys to be stroked serially. (A shift key acting on a single character is effective because a lower-case character nearly always follows an upper-case character. (An exception occurs in Spanish where sentences may begin with an inverted question mark or an inverted exclamation point.) Since most capitals are consonants, the shift key is located on the vowel side of the keyboard. This in turn indicates that common symbols on the number row ($, %, =) should be set on the consonant side of the keyboard, so they can be entered by a pair of alternate-hand strokes.

Capitals may be rapidly inputed because there is only one shift key, and the sequence (space, shift) can be easily executed by the thumb and third finger of the left hand. This is a marked asset in processing newspaper and magazine texts, which contain a host of capitals due to the prevalence of personal, place, and organizational names in journalistic copy.

The letter arrangements presented herein allow upper-case characters to be generated on electric typewriters using a single shift key. If this shift disengages after each stroke, serial stroking can be employed. If a conventional shift key is retained, the third finger can hold down the shift key while another finger strikes the upper-case character key. When this key would be normally struck by the third finger of the left hand (the *e* or five key in English), the third and fourth finger can operate the required keys.

On the programmed keyboards of this invention, a single stroke replaces the fixed sequence of strokes occurring after certain punctuation marks, such as the transition from one sentence to another, which usually requires a period, two spaces, and a shift. These four strokes are generated automatically by a lower-case period— eliminating three superfluous strokes. The period needed to input decimals and abbreviations are produced by an upper-case period, which is easily stroked as a digraph, since the shift and period lie side by side on the top letter row.

Operating the lower-case comma, colon, or semi-colon keys automatically generates a space following a comma, colon, or semi-colon, respectively. The comma needed in numbers and quotations is produced by an upper-case comma, or by stroking the back space key, which can also delete the space after a colon or a semi-colon.

A single chord stroke replaces the fixed sequence of strokes needed to go from one paragraph to another. The key-pair (shift, period) executed by the third and fourth finger generates the output (period, carriage return, tab, and shift). This chord may be readily stroked because the shift and period keys lie side by side on the top letter row. Passing from one pargraph to another in a single stroke is particularly helpful in processing newspaper copy where paragraphs are often only one or two sentences long.

A different chord generates the sequence (period, two carriage returns, and a shift) needed to pass from one paragraph to another in single-spaced business letters. This sequence is produced by the chord (shift, question mark) executed by the second and third fingers.

A programmed keyboard can eliminate the need to operate the carriage return key at the end of each line. Such programming is now incorporated in cathode ray terminals which automatically transfer words to the next line of the screen when they terminate beyond the end of a line (wrap-around). On word processing equipment, an analogous procedure is employed when the text is played out in the "adjust mode." When either a space or a hyphen is sensed within a given number of spaces from the end of a line (the hot zone), the machine interprets a space as a carriage return, and generates a carriage return after a hyphen.

A similar procedure is adopted on the programmed keyboards of this invention. When a space or hyphen key is struck within a given number of spaces from the end of a line (which may be varied), the machine automatically generates a carriage return. This eliminates the necessity of moving the thumb from its home home position to strike the carriage return key, which occurs about every 60 to 75 characters. It also allows operators to input the text without worrying about reaching the end of a line. This automatic carriage return may be eliminated by striking the margin release key to permit input beyond the hot zone.

Characters may be stored internally in the machine (rollover) and played out after the system has passed from the end of one line to the beginning of the next one. This avoids the danger of losing characters while the system is changing lines, and permits operators to continue keyboarding while the machine is shifting lines. Internal character storage, which is often employed on electronic keyboards, enables a chord to be entered by one hand while the machine is processing a previous chord stroked by the opposite hand. Since each chord produces two or more characters, internal storage allows input to approach the maximum machine output when these rates are comparable.

Chording

A majority of the one-hand digraphs on the keyboards of this invention involve characters lying directly under the fingers. Many of these digraphs can be processed efficiently by chord strokes in which two keys under the fingers are operated simultaneously. Although cord stroking has been used for a long time in stenographic machines, telegraphic terminals, and chord typewriters to reduce the number of keys needed to generate a given set of characters, the keyboards of this invention employ chords that can be learned far more readily because their output coincides with the output of the same keys operated serially in a majority of cases.

The method of converting chords into multiple characters will depend on the device attached to the keyboard. It will be different for an electronic typewriter, a CRT terminal, a paper tape perforator, or a computer input station recording data on magnetic tape or disks. Since the output of individual chords is closely related to the keys simultaneously stroked, chording may be readily introduced in equipment containing sold-state electronic components. It can also be added to devices originally designed for single stroke operation.

The two-key chords used in this invention are based on a statistical analysis of letter frequencies that minimize successive strokes by the same hand and combine the ease of chording with the speed of alternate-hand stroking. Eight easy chords are employed involving a pair of keys lying under the fingers of each hand. They are: simultaneous operation of the thumb key and a home row key (four strokes); simultaneous operation of two adjacent keys on the home row (three strokes); and simultaneous operation of keys under the little and fourth fingers (one stroke). Experimental measurements show that these eight two-finger chords may be executed quickly and accurately. (Additional three-finger chords may be added for languages, such as German, to input common three-character sequences.)

These chords may be completed by a single movement of the hands almost as rapidly as a single stroke. Since a chord usually generates two characters, each chord effectively eliminates one of the strokes required when keys are operated sequentially. When chording is used, the keyboard must be buffered, however, to introduce a time delay that will enable the machine to determine whether a pair of strokes should be interpreted as a chord, or as a pair of individual strokes. This time delay will not reduce the output rate when characters are stored internally, as long as the sum of the delay time and the output time is less than the mean character input time. Thus the output time on an electronic typewriter might be .03 sec. (corresponding to 33 characters a second) and the delay time .01 sec. Their sum, .04 sec., fixes the maximum through-put rate at 25 characters a second, or 250 six-character words a minute. Internal storage is thereof important in achieving maximum processing rates—especially when chording is used, and keyboard input and machine through-put rates are comparable.

Double letters form a significant class of one-hand digraphs, accounting for 1.7% of the letters and spaces in English. The commonest repeated letters are 11, ee, oo, ss, and tt. On conventional keyboards, these double letters cannot be produced quickly because repeated strokes by the same finger require more time than strokes by alternate hands. On programmed keyboards, double letters may be entered rapidly by holding down the corresponding letter keys to instruct the machine to generate the double letters. This procedure leads to faster input because the time that a key must be depressed is much shorter than the time required to complete a double stroke. Holding a key down is much simpler kinesthetically than making a repeated stroke on the same key, particularly for double letters lying outside the home position, such as 11, pp, and ff. Consequently double letters can be processed more efficiently on programmed keyboard than on conventional keyboards. Generating double letters automatically is a valuable asset in foreign languages where repeated letters are common. Examples include Dutch which has many double vowels, and Swedish which has many double consonants.

Operators can swiftly learn to produce repeated letters by holding down a letter key because of the ease of associating double letters with an extended key stroke. Only a limited group of double letter combinations must practiced to learn the method, since the same general motor response applies to all repeated letters. This is analogous to learning the shift key, where only a small set of capitals must be practiced to master the method. since automatic input or repeated letters is easy to learn, this feature is applied to the entire alphabet. (A possible exception is the *x*, which may be made to repeat as long as the *x* key is held down.)

Double letters occur often enough in typical English texts to reinforce initial learning of the extended stroking response. As a result, rapid entry will be maintained after early training because of the prevalence of repeated letters. Employing an extended stroke to generate double letters significantly reduces the number of successive strokes that must be made on keys outside the home position, and is a natural extension of chording in which a pair of keys are struck simultaneously to produce a digraph consisting of two different characters.

The output of particular key-pairs is determined by the digraph frequencies in the language. A small number of common one-hand digraphs are obvious candidates for chording. Most of these digraphs involve characters on the home keys, since they appear more often than the letters on other keys. The assignment of particular digraphs to specific key-pairs of straightforward in most alphabetic languages because the appearance of vowel-pairs and consonant-pairs differ sharply depending on their order. This is expected on linguistic grounds, since vowels and consonants represent phonemes (sounds) that are usually associated with initial or terminal positions.

The choice of digraphs associated with particular chords may be illustrated using English as an example. To make the selection process clearer, the frequencies of individual digraphs per **100,000** letters and spaces (taken from Table 5) are listed after each digraph.

On the vowel side of the keyboard, half the chords involve the space and a home-key vowel. The key-pair (*e*, space) produces space then *e* (3524); (space, *a*) produces space then *a* (2010); (space, *i*) produces space then *i* (1187); (space, *o*) produces space then *o* (1248). In addition, the key-pair (*i*, *o*) generates io (447); and (*e*, *a*) generates ea (472). Since oe (29) and eo (42) rarely occur, the digraph ou (634) is assigned to the chord (*o*, *e*). This eliminates the need to move the thumb from the home position to strike the *u* in ou, and simplifies inputing the common word you. Since the digraph *y*-space (1027) appears much more often than ia (106) and ai (230), *y*-space is alloted to the chord (*i*, *a*). This reduces motion of the little finger to input this digraph, since the *y* ends two out of three of the words in which it appears.

Chords on the consonant side of the keyboard are chosen in a similar fashion. The key-pair (*t*, *h*) produces th (2337); (*s*, *t*) produces st (720); (*r*, *s*) produces rs (270); (*n*, *t*) produces nt (618); and (*n*, *s*) produces ns (294). Since nh (7) and hn (18) are very rare, the digraph nd (851) is assigned to the key-pair (*n*, *h*), reducing movement of the fourth finger to strike the *d*. Likewise, since ng (664) occurs more frequently than rn (107) and nr (6), the digraph ng is alloted to the chord (*n*, *r*). This choice reduces the need of the little finger to strike the *g*, since ng appears in two out of every five words containing a *g*. Finally, since ch (378) occurs more often than hr (58) and rh (12), the digraph ch is assigned to the chord (*h*, *r*), reducing the movements of the second finger to strike the *c*.

The output of eleven of the sixteen chords can be generated by serially stroking the two keys involved. In four of the chords, the output includes one of the keys simultaneously struck. In only one case is the output completely different from the pair of keys. This is quite different from stenographic machines and chord typewriters where there is little relation between single and multiple key strokes. Because of the large number of arbitrary chord combinations that must be memorized in these devices, stroking facility is difficult to acquire. This is not true on the ten-finger keyboards of this invention where there is a close connection between chord input and output.

For the English language, the output of eleven of the chords is identical with the home keys stroked. These chords may be readily mastered once the home keys have been learned. Since each chord generates two characters and is produced by simultaneously operating a pair of keys, each character reinforces the association between the visual stimulus and the required motor response. Although the output of four of the sixteen chords includes only one of the keys stroked, in three of these cases, the other character is adjacent to the key chorded. In only one instance (*y*-space), is the output different from the keys stroked—and here, the *y* is next to one of the keys chorded. This close relation between input and output insures that chords will be mastered easily and lead to rapid, accurate entry of common one-hand digraphs.

When the output of a chord does not coincide with the keys stroked separately, two alternate digraphs may be produced by sequentially operating the same keys. Significant kinesthetic interference does not occur between chords and serial strokes in English because digraphs associated with chords appear much more often than those associated with serial strokes. This may be confirmed by comparing their respective digraph frequencies. (In the following equations, the space is represented by a hyphen.)

On the vowel side of the keyboard:

e–/e– = **8**, –a/a– = **5**, –i/9– = **11**, –o/o– = **7.7**, io/oi = **8**, ea/ae = **80**, ou/(oe+eo) = **9**, y–/(ia+ai) = **3**,

On the consonant side of the keyboard:

th/ht = **23**, st/ts = **3.5**. rs/sr = **130**, nt/tn = **100**, ns/sn = **02**, nd/(nh+hn) = **32**, ng/(nr+rn) = **6**, ch/(nh+rh) = **6**,

From these ratios, it is clear that chords occur far more often than serial strokes on the same home keys. Therefore chord and serial digraphs will not be mistakenly interchanged, which would happen if their frequencies were comparable. In only one case, (*o* and space), are serial and chord digraphs comparable. This is due to the appearance of such common serially stroked words as to, no, and so, along with such common chorded words as of, on, and or. But even here, the chord occurs nearly twice as often as the serially stroked sequence.

Chording is an efficient means of processing one-hand digraphs. A small set of sixteen chords, eight on each hand, generates a majority of one-hand digraphs in English. These chords, which are produced by simultaneously operating a pair of home keys, may be learned once individual key locations have been mastered.

The utility of the ten-finger keyboards of this invention are significantly extended because they can be used effectively on serially stroked keyboards, as well as programmed keyboards. Although each character must be individually stroked on serial keyboards for devices, such as electric typewriters, the ten-finger arrangement permits common digraphs to be executed rapidly by strokes on home keys. Frequent digraphs involving a home thumb stroke followed by a stroke on the home row include in English a space followed by *a*, *i*, or *o*; and an *n* followed by a *d*, *t*, *s*, or *q*. Another set of common digraphs can be completed by strokes on adjacent home keys going from the little finger to the fourth finger. Examples in English include: io, ea, rs, st, and th.

## Numerical Analysis

The distribution of various one-hand strokes may be determined from the digraph frequencies of the English language recorded in Table 5. This analysis disregards punctuation, numbers, shifts, and controls, which may account for 5% of the strokes in ordinary texts. These strokes are omitted because their frequency will vary widely depending on the nature of the material being processed and the programming features on the keyboard.

Table 6 lists the percentages of various one-hand strokes. These figures reveal that grouping vowels and consonants on opposite sides of the keyboard substantially reduces the proportion of one-hand motions because of the tendency of vowels and consonants to alternate. Since half of the characters appearing in typical texts belong to the left hand and half to the right hand, 25% of the digraphs would appear on each hand if character-pairs were randomly distributed. Instead, 15.6% of the digraphs occur on the left hand, 13.9% on the right hand, and a total of 29.5% on both hands. This is three-fifths the percentage for a random arrangement of characters, and confirms the effectiveness of separating vowels and consonants.

Table 6 lists the percentage of various one-hand strokes. They are classified into chords (including double letters), and pairs of successive strokes containing two, one, or no home-key strokes. Chords on the left hand account for 11.0% (or two-thirds) of the left hand digraphs, and chords on the right hand for 7.4% (or half) the righthand digraphs. Thus, while 29.5% of the text will consist of one-hand digraphs, 18.4% may be executed by chords, and 11.1% by one-hand strokes, so that 89% of the letters and spaces may be processed by alternate-hand or chord strokes.

Since each chord generates two characters, chording effectively eliminates 18.4% of the strokes needed when serial input is employed. Another 4% are eliminated by automatically generating the space after a comma and using a single stroke or chord to go from one sentence or paragraph to another. Thus a programmed keyboard for the English language requires only four-fifths as many strokes as a conventional keyboard.

On the ten-finger keyboard, 11.1% of the digraphs must be entered by successive one-hand strokes, of which 3.9% involve two home-key strokes; 5.8% one home and one outside stroke; and 1.4%, two outside strokes. These serial sequences may be readily executed because letters outside the home position have been arranged so that significant one-hand combinations are easily stroked. Examples include digraphs with one outside letter, such as ex, nc, ct, fr, pr, and wh, and digraphs with two outside letters, such as ld, bl, pl, and mp.

Although the left hand performs slightly more strokes than the right hand (when punctuation marks are taken into account), the greater dexterity of the right hand is utilized by assigning it more one-hand sequences requiring serial strokes outside the home position. The right hand executes 3.9% of the digraphs containing one outside stroke and 1.3% containing two outside strokes; whereas the left hand is alloted 1.8% of the digraphs that involve one outside key, and only **0.1%** involving two outside keys.

On the ten-finger keyboard, nearly four-fifths of the letters and spaces (78.1%) are generated by home-key strokes, and a fifth (21.4%) by keys outside the home position. In contrast, two-thirds of the strokes (66.9%) on the Dvorak-Dealey keyboard are made on home keys, and one-third (33.1%) on outside keys. This increase in outside strokes is understandable because the Dvorak keyboard possesses only nine home keys (*a*, *o*, *e*, *i*, and space on the left hand; and *h*, *t*, *n*, and *s* on the right hand). On the Dvorak keyboard, no vowel digraphs and only three common consonant digraphs (th, nt, and ns) lie on adjacent keys. Furthermore a number of significant digraphs are awkward to stroke (ct, bl, fr, gh, and up) because letters are arranged on three staggered key rows.

The flaws of the standard keyboard are much more important because this keyboard must be displaced before a new one can take its place. The universal keyboard may be described as an alphabetical array of keys split between two hands. The left hand contains the letters *a* through *g*, *q* through *t*, and *v*, *x*, and *z*. The right hand includes the letters *h* through *p*, *u* and *y*, plus the space key. Since common vowels and consonants are assigned to both hands, thousands of English words can be stroked using the fingers of a single hand. Furthermore, approximately half the digraphs occur on individual hands which is the proportion that would be expected if the letters on the keyboard were randomly distributed.

Dvorak and Dealey analyzed the weaknesses of the universal keyboard in U.S. Pat. No. (2,040,248). They examined successive strokes and showed that 28% of the digraphs on the keyboard are hard to execute. However, they restricted their analysis to two-character sequences.

Three-character sequences on the same hand are even more illuminating. Three-character combinations (trigraphs) reveal the presence of host of complex finger motions that impede the acquistion of keyboard skill. These trigraphs have been counted by computer for the one-million word sample (containing 5.7 million characters) used in compiling the digraph frequencies given in Table 5. These sequences are bounded by spaces at the beginning and end of words, i.e., they ignore the trigraphs: letter, space, letter.

These three-character combinations are tabulated as a function of their appearance. On the standard keyboard, 99 trigraphs occur more than 40 times per 100,000 characters and comprise 10.1% of the letters and spaces. An additional 103 trigraphs appear at least 20 times, amounting to 3.1% of the text. A further 126 trigraphs appear more than ten times, amounting to 1.8% of the letters and spaces. Thus a total of 328 one-hand trigraphs (bounded by spaces) account for 15% of the text.

These trigraphs include such common sequences as ate, ter, ere, and was, as well as a space followed by the frequent prefixes in and un. Five out of fifty of the commonest words in English (in, on, no, you, and him) can be stroked by the right hand, along with the spaces bounding these words. Although particular trigraphs do not appear often, there are so many on the standard keyboard, they comprise moer than one-seventh of the letters and spaces in typical texts. This army of trigraphs is too large to be mastered individually. Collectively they force the fingers to follow complex paths paths in processing alphabetic material.

This host of trigraphs mitigates against rapid input and quick learning. Such kinesthetic barriers are not present on the keyboards of this invention where the segregation of vowels and consonants leads to easy stroking sequences. The absence of difficult finger motions is indicated by the small number of one-hand trigraphs. These three-character combinations are tubulated for English as a function of frequency in Table 7. Only 12 one-hand trigraphs appear more than 40 times per 100,000 letters and spaces, amounting to 1.2% of the text. Another 12 digraphs occur more than 20 times and account for 0.4% of the text. An additional 14 appear more than 10 times, amounting to another 0.2% of the text. Thus a total of 38 trigraphs account for 1.8% of the letters and spaces. This compares with 328 one-hand trigraphs on the standard keyboard, comprising 15% of the text.

These statistics prove that assigning vowels and consonants to opposite hands is a powerful means of reducing triple strokes by the same hand. If character sequences occurred randomly, one-hand trigraphs would account for 25% of the text. Instead they account for less than 3% of the text (when trigraphs across words are included). This great decrease, which is due to the alternation of vowel and consonant phonemes, confirms the effectiveness of separating vowels and consonants on optimum keyboards. Most of the one-hand trigraphs in English and the Romance languages can be readily processed, since they usually consist of a home-key stroke and a digraph that may be chorded (or sequentially stroked on home keys when chording is not available). Therefore, as far as input rates are concerned, triple strokes by the same hand may be safely disregarded.

In English, 10 out of the 38 significant one-hand trigraphs begin with the letter *n*, and 8 of these include an initial digraph that may be chorded. This confirms the choice of *n* as a thumb key. The only problem word is you, which includes three vowels and two spaces stroked by the left hand. Although these five characters contain three trigraphs that comprise 12% of the one-hand trigraphs on the ten-finger keyboard, they do not significantly impair the total processing rate because they contain a chord stroke and represent only 0.2% of the letters and spaces.

This analysis neglects the trigraphs (letter, space, letter) occurring across words. Most of these trigraphs, which amount to less than 1% of the text in English, can be readily entered on the ten-finger keyboard because they usually consist of a chord terminating a word (*e*-space or *y*-space) followed by a home-key vowel beginning a word (*a*, *i*, or *o*). Consequently these digraphs do not hamper input. Since the transition between sentences and paragaphs has also been simplified, there are not kinesthetic obstacles to high performance on the ten-finger keyboards of this invention.

The numerical methods used to analyze stroking patterns in English may be applied to other languages as well. Such analysis furnishes an objective, quantitative comparison between competing designs, and delineates the effectiveness of arranging characters according to their statistical behavior. It is also helpful in fashioning effective instruction materials.

Foreign Language Keyboards

The procedure of designing an optimum keyboard for English may be utilized for other alphabetic languages. Since this method has been described in detail for English, only salient features will be noted for German, French, Italian, Spanish, and Portuguese.

These languages employ diacritical marks, which usually accompany vowels. On the standard keyboard, letters containing diacritical marks are generally alloted individual keys. (In German, the *ä*, *ö*, and *ü* are assigned keys, along with the *a*, *o*, and *u*.) Using separate keys for letters containing diacritical marks increases the number of key locations that must be learned. Since letters without diacritical marks are much commoner than those with them, this practice leads to keyboards with a large number of rare alphabetic keys which significantly extends the time required to gain stroking facility.

The foreign keyboards of this invention use "dead" keys for diacritical marks. These keys include diacritical marks for both upper and lower-case characters. The keys generate the diacritical marks, but do not advance the system in the horizontal direction. Letters with diacritical marks are produced by striking the corresponding diacritical and letter keys in succession. Upper-case diacritical keys do not return the system to the lower case, so that only a single shift is needed to enter an upper-case letter containing a diacritical mark. Since these marks usually appear with vowels proceded by a consonant, diacritical marks are placed on the vowel side of the keyboard, arranged to minimize successive strokes by the same finger. Thus on the German keyboard, the umlaut is set on the upper letter row, assigned to the same finger as the *e* because the umlaut does not appear with the *e*.

Employing a separate key for each diacritical mark, rather than one for each letter-diacritical combination reduces the number of keys needed to cover the alphabet, particularly in the Romance langages where many letters contain diacritical marks. A single accent acute key (´) can generate *á*, *é*, *ó*, and *í* in Spanish and Portuguese. An single accent grave key (`) can produce *à*, *è*, *ò*, and *ì* in Italian; and a single circumflex key (^) generate *â*, *ê*, and *ô* in French.

When a diacritical mark appears with only a single letter, such as *ñ* in Spanish and *ç* in French and Portuguese, this letter is assigned to the same finger as the letter without the diacritical mark. This furnishes a helpful associative link connecting the two letters with the same finger, but does not encourage substitution errors because the two letters appear with widely differing frequencies.

Using dead keys for the diacritical marks eliminates superfluous keys because a single diacritical mark may combine with several letters. Since specific diacritical marks appear with moderate frequencies (ranging from a fraction of 1% to 2%), diacritical keys are stroked often enough in typical texts to reinforce initial learning of these keys. Consequently a large alphabet containing many letters with diacritical marks does not seriously impair keyboard performance.

Many European languages contain rare letters that appear only in words of foreign origin. The *k* and *w* are examples in the Romance languages. While it is desirable to include such letters on foreign keyboards, they occur so infrequently in representative texts (less than 0.1%) that they do not influence input rates. Since the location of these rare letters may be varied without significantly effecting processing or stroking efficiency, these letters as well as minor punctuation marks are not shown on the foreign keyboards of this invention. These omitted letters are *k* and *w* in French and Spanish; *k*, *w*, and *y* in Portuguese; *j*, *q*, *x*, and *y* in German; and *j*, *k*, *w*, *x*, and *y* in Italian.

Languages belonging to the same linguistic family exhibit statistical similarities. Thus the full repertory of chords employed in English is not required in the Romance languages because they have only a limited number of common one-hand chords. The Romance languages also have a higher proportion of vowels and vowel-vowel digraphs than the Germanic and Slavic languages, which in turn have a larger fraction of consonant-consonant digraphs. Despite such similarities, each language possesses unique linguistic features that must be taken into account in designing an optimum keyboard. Therefore each of the foreign keyboards of this invention are discussed briefly--focusing on aspects that effect input rates and the successful application of kinesthetic principles and linguistic statistics.

Italian: The basic keyboard is shown in FIG. 5 (the rare letters *j*, *k*, *w*, *x*, and *y* are omitted). The *i* is set between the *o* and the *a* for easy input of the common digraphs io and ia. The *s*, *t*, and *r* are assigned to the second, third, and fourth fingers of the right hand for swift entry of st, tr, rt, and str. The *c* and the *h* lie side by side on the upper letter row so the common digraph ch can be stroked by the third and fourth fingers. Since nine out of ten words end in vowels, major punctuation marks (period, comma, and question mark) are placed on the consonant side of the keyboard, with the period and comma on the ends of the top letter row. On the vowel side of the keyboard, the accent acute ( ´ ) is between the *e* and *a* keys because it appears as *é* and *á*; and the apostrophe is on the top letter row because it occurs frequently as a connective joining articles and nouns.

Portuguese: The basic keyboard is shown in FIG. **6** (the rare letters *k*, *w*, and *y* are omitted). The *t* is chosen as a home key, rather than the *m* that occurs as often, because the *t* appears in the common digraphs nt and st. The *s*, *t*, and *r* lie side by side to facilitate input of st, tr, and str. The frequent digraphs ei, oe, ia, and ao fix the serial arrangement of the vowels from the little to the fourth fingers as *e*, *o*, and *a*. The diacritical marks ( ⁄ ), ( ∖ ), and ( ∧ ) are arranged to minimize successive strokes by the same finger. In particular, the circumflex ( ∧ ) is assigned to the fourth finger because it appears in *ê* and *ô*, and the tilde ( ~ ) is alloted to the little finger because it occurs in *ã*.

Spanish: The basic keyboard is shown in FIG. **7** (the rare letters *k* and *w* are omitted). The *t* is chosen as a home key letter instead of the *l* that occurs more often, or the *c* that has a comparable frequency, because the *t* forms more common digraphs with other home letters, notably nt and st. The *i* is set between the *a* and *o* for easy stroking of the frequent digraphs ia and io. The *y* is on the consonant side of the keyboard because the *y* usually appears alone as a monosyllabic word (meaning "and"). The *r* is selected as the home-thumb key (rather than the *n* as in other language) because the *r* appears in a large number of digraphs (including pr, br, gr, rd, and rt). A novel feature in Spanish is the use of the inverted quesmark (¿) and the inverted exclamation point (¡) at the beginning of interrogatory and exclamatory sentences. These upper-case punctuation marks are placed on the top letter row alongside the shift key, so they can be produced readily by successively striking the shift and corresponding punctuation key. Only a single shift stroke is needed at the beginning of interrogatory and exclamatory sentences because the inverted question and inverted exclamation keys do not return the system to low-case operation.

French: The basic keyboard is shown in FIG. **8** (the rare letters *k* and *w* are omitted). The common digraphs, ai, ie, eu, and ue determine the serial arrangement of vowels from the little to the fourth finger as *a*, *i*, *e*, and *u*. The accent acute ( ⁄ ) is assigned to the fourth finger because it does not appear with the *u*, and the accent grave ( ∖ ) to the second finger because it does not appear with the *i*. Similarly, the circumflex ( ∧ ) is alloted to the little finger because it does not occur with the *a*. On the consonant side of the keyboard, the *p* is assigned to the second finger and the *c* to the third finger on the upper letter row for simple stroking of the digraphs *pr*, *ps*, *cl*, and *ch*.

German: The basic keyboard is shown in FIG. **9** (the rare letters *j*, *q*, *x* and *y* are omitted). The vowels *a*, *u*, *e* and *i* are serially arranged from the little to the fourth finger for easy entry of the common digraphs au, ei, and ie. Since all nouns are capitalized, the shift key is placed at the end of the home row for swift sequential operation of the space and shift keys. The umlaut ( ·· ) is set on the top letter row over the *e* (instead of the shift as in other languages) because the umlaut does not appear with the *e*. The *n* is chosen as sthe home thumb-key, since it occurs much more often than other consonants; the *s* and *t* lie side by side on the home row for quick entry of st. Although more consonant digraphs and trigraphs appear in German than in English, or the Romance languages, the combinations ch, sch, and sch account for a substantial proportion of these one-hand strokes. Their input is expedited by alloting the *t* to the third finger and the *h* to the fourth finger on the home row, and the *c* to the third finger on the top letter row. This choice permits ch, sch, and cht to be readily stroked, even if they are bounded by other consonants.

## Keyboard Training

The keyboards of this invention minimize finger motions and maximize alternate hand strokes, leading to faster learning and greater performance by operators of average ability. On these keyboards, the hands hover over home keys as fingers make simple, independent movements from the home position. The resulting stroking patterns differ sharply from the complex motions required on the universal keyboard. As a result, individuals who already know the standard keyboard will experience a minimum motor intererece in switching to the new keyboard—and previously established habit patterns will not impede learning the new key configuration.

Instruction capitalizes on a central feature of the invention: the independence of stroking motions that permits simple movements to be practiced separately and then combined to input alphabetic texts. Lessons can start with easy motions that occur often, and proceed to more difficult movements appearing less frequently. Exercises can concentrate initially on alternate-hand strokes on home keys, beginning with keys at the edges of the hand (the thumb, the fourth, and little fingers), that are easiest to disinguish kinesthetically—and progress to keys in the middle of the hand (the second and third fingers).

Limiting motor alternatives accelerates learning and lightens the processing load on the brain, leading to swift acquisition of chain stroking. Experimental measurements of reaction times reveal that keyboard responses to visual stimuli are proportional to the logarithm of the number of available response channels. Therefore practicing a small number of alternatives hastens the formation of appropriate motor reflexes. This training strategy succeeds on the ten-finger keyboard because representative texts may be processed by simple, independent finger motions. (It falls on the standard keyboard where complex finger movements cannot be broken down into simpler elements.)

Since input is reduced to a set of simple finger motions, basic factors governing learning rates and ultimate performance may be isolated and measured. Empirical studies reveal marked differences in the dextral abilities of violinists and pianists. Similar differences exist for keyboard operators. These differences may be used to select trainees from a large pool of employees who will attain high entry rates in a short time. Diagnostic tests may be administered prior to training to identify gifted operators by measuring the speed with which they complete repetitive strokes on home keys and establish digital associations. Choosing individuals with natural ability will yield better results than a random selection, and help offset the cost of training employees on new equipment.

Exercises can cover the keyboard in accordance with the frequency of individual letters and chords. Lessons may start with common characters on home keys, continue with medium frequency letters on adjacent keys, then treat chords, and finally rare characters at the

Table 3-continued

Cumulative Frequencies of Commonest Characters in Six Languages

| English | German | French | Italian | Spanish | Portuguese |
|---|---|---|---|---|---|

I. Space and Four Vowels
II. Five Consonants
III. Space, Four Vowels, and Five Consonants

Table 4

Maximum and Minimum Letter Percentages in Nine Languages

| | |
|---|---|
| a: 13.4 (Portug.) – 5.1 (German) | b: 1.9 (German) – 0.5 (Portug.) |
| c: 4.4. (Italian) – 0.1 (Danish) | d: 6.4 (Danish) – 3.4 (French) |
| e: 19.3 (Dutch) – 10.2 (Swedish) | f: 2.4 (English) – 0.8 (Spanish) |
| g: 4.2 (Danish) – 0.7 (Spanish) | h: 5.6 (English) – 0.7 (Spanish) |
| i: 11.3 (Italian) – 5.7 (Swedish) | j: 0.7 (Swedish) – xxx (Italian) |
| k: 4.1 (Danish) – xxx (French) | l: 7.5 (Italian) – 3.5 (Swedish) |
| m: 4.4 (Portug.) – 2.4 (Dutch) | n: 11.6 (Dutch) – 5.5 (Portug.) |
| o: 11.5 (Portug.) – 2.1 (German) | p: 3.0 (French) – 0.6 (German) |
| q: 1.5 (Portug.) – xxx (Swedish) | r: 8.6 (Swedish) – 5.4 (Dutch) |
| s: 7.9 (French) – 3.1 (Dutch) | t: 9.4 (English) – 4.2 (Spanish) |
| u: 6.7 (French) – 1.5 (Dutch) | v: 3.0 (Swedish) – 0.8 (German) |
| w: 1.9 (English) – xxx (Spanish) | x: 0.2 (English) – xxx (German) |
| y: 1.8 (English) – xxx (Italian) | z: 1.7 (German) – xxx (Swedish) |

(xxx represents a value of less than 0.1)

Table 5

English Digraph Frequencies per 100,000 Letters and Spaces

| First \ Second | — | a | b | c | d | e | f | g | h |
|---|---|---|---|---|---|---|---|---|---|
| — | 0 | 2010 | 805 | 843 | 528 | 426 | 714 | 300 | 949 |
| a | 498 | 1 | 140 | 286 | 284 | 6 | 46 | 132 | 8 |
| b | 19 | 109 | 10 | 0 | 1 | 389 | 0 | 0 | 0 |
| c | 92 | 331 | 0 | 41 | 0 | 396 | 0 | 0 | 378 |
| d | 1835 | 104 | 2 | 1 | 32 | 478 | 1 | 20 | 3 |
| e | 3524 | 472 | 15 | 275 | 813 | 271 | 96 | 72 | 16 |
| f | 750 | 111 | 0 | 0 | 0 | 150 | 92 | 0 | 0 |
| g | 546 | 100 | 1 | 0 | 1 | 240 | 1 | 20 | 176 |
| h | 472 | 653 | 4 | 2 | 1 | 2139 | 1 | 0 | 1 |
| i | 106 | 151 | 55 | 419 | 220 | 230 | 126 | 175 | 1 |
| j | 2 | 17 | 0 | 0 | 0 | 29 | 0 | 0 | 1 |
| k | 163 | 13 | 1 | 0 | 0 | 181 | 2 | 1 | 3 |
| l | 556 | 322 | 5 | 6 | 202 | 555 | 41 | 4 | 1 |
| m | 297 | 362 | 61 | 3 | 0 | 519 | 3 | 1 | 0 |
| n | 1530 | 196 | 3 | 244 | 851 | 481 | 34 | 664 | 7 |
| o | 737 | 50 | 62 | 97 | 121 | 29 | 686 | 52 | 16 |
| p | 108 | 197 | 0 | 0 | 0 | 302 | 1 | 0 | 53 |
| q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| r | 1030 | 408 | 17 | 67 | 124 | 1168 | 20 | 60 | 12 |
| s | 2248 | 153 | 6 | 93 | 5 | 558 | 9 | 1 | 235 |
| t | 1641 | 331 | 2 | 27 | 1 | 749 | 5 | 1 | 2337 |
| u | 66 | 77 | 57 | 108 | 59 | 85 | 12 | 94 | 1 |
| v | 6 | 75 | 0 | 0 | 0 | 534 | 0 | 0 | 0 |
| w | 160 | 327 | 1 | 0 | 3 | 247 | 1 | 0 | 258 |
| x | 22 | 15 | 0 | 16 | 0 | 11 | 0 | 0 | 2 |
| y | 1027 | 12 | 6 | 6 | 3 | 77 | 1 | 1 | 1 |
| z | 5 | 14 | 0 | 0 | 0 | 35 | 0 | 1 | 0 |
| Totals | 17,607 | 6,627 | 1,264 | 2,561 | 3,269 | 10,294 | 1,922 | 1,607 | 4,479 |

| First \ Second | i | j | k | l | m | n | o | p | q |
|---|---|---|---|---|---|---|---|---|---|
| — | 1187 | 95 | 88 | 414 | 693 | 378 | 1248 | 687 | 34 |
| a | 230 | 6 | 75 | 649 | 185 | 1270 | 3 | 117 | 1 |
| b | 66 | 11 | 0 | 155 | 2 | 0 | 142 | 0 | 0 |
| c | 155 | 0 | 110 | 97 | 1 | 1 | 488 | 0 | 2 |
| d | 291 | 4 | 0 | 28 | 11 | 19 | 138 | 1 | 1 |
| e | 109 | 3 | 16 | 349 | 232 | 907 | 42 | 107 | 29 |
| f | 181 | 0 | 0 | 42 | 0 | 0 | 322 | 0 | 0 |
| g | 96 | 0 | 0 | 40 | 4 | 39 | 99 | 0 | 0 |
| h | 563 | 0 | 0 | 9 | 8 | 18 | 342 | 1 | 0 |
| i | 1 | 1 | 39 | 299 | 218 | 1554 | 447 | 57 | 8 |
| j | 2 | 0 | 0 | 0 | 0 | 0 | 38 | 0 | 0 |
| k | 71 | 0 | 1 | 10 | 1 | 40 | 7 | 1 | 0 |
| l | 402 | 0 | 19 | 417 | 20 | 4 | 254 | 14 | 0 |
| m | 207 | 0 | 0 | 3 | 59 | 6 | 225 | 136 | 0 |
| n | 221 | 7 | 40 | 47 | 15 | 62 | 295 | 4 | 3 |
| o | 57 | 4 | 52 | 232 | 356 | 1071 | 178 | 141 | 1 |
| p | 88 | 0 | 1 | 166 | 11 | 0 | 214 | 91 | 0 |
| q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| r | 436 | 0 | 62 | 65 | 102 | 107 | 471 | 27 | 1 |
| s | 345 | 0 | 33 | 45 | 45 | 15 | 251 | 120 | 7 |
| t | 753 | 0 | 0 | 75 | 20 | 6 | 713 | 2 | 0 |
| u | 67 | 0 | 1 | 226 | 81 | 271 | 7 | 94 | 0 |
| v | 157 | 0 | 0 | 0 | 0 | 0 | 41 | 0 | 0 |
| w | 261 | 0 | 1 | 9 | 1 | 62 | 163 | 1 | 0 |
| x | 18 | 0 | 0 | 0 | 0 | 0 | 2 | 42 | 0 |
| y | 22 | 0 | 1 | 9 | 15 | 8 | 109 | 13 | 0 |

extremities of the keyboard. Since a majority of strokes in typical texts will lie on home keys hidden from view, instruction will result automatically in touch typing.

Basing lessons on kinethetic principles and linguistic statistics insures that practice exercises will match letter sequences occurring naturally in the language. Exercises may be arranged in groups of related and contrasting strokes to expedite conversion of visual stimuli into digital responses. Such groups include alternate vs. same hand motions; home key vs. other key strokes; single strokes vs. two-key chords; strokes at the edges of the hand (thumb, fourth, and little finger) vs. strokes at the center of the hand (second and third fingers); and chords executed by the thumb and another finger vs. chords executed without the thumb.

Practicing on related sets of fingers motions aids in establishing motor associations and strengthens the weak cerebral-dextral link. The effectivensss of particular exercises may be determined by measuring the speed that specific digraphs are executed as a function of practice. These measurements supply a microscopic profile of keyboard facility and pinpoint any difficulties that may impede learning. Such measurements can also determine the contribution of specific stroking exercises to total processing rates.

Instruction on the ten-finger keyboards of this invention can focus on a limited set of motions which may be mastered before adding other strokes. Practicing a small group of motions leads to a rapid increase in input rates. This rate of increase diminishes with additional practice, as stroking rates approach their asymptotic values with extended practice. This negatively accelerated curve, which is characteristic of motor learning, may be used to establish optimum conditions for advancing from one exercise to another. Such conditions can take account of individual differences in learning and stroking ability to provide a personalized instruction program that leads to maximum input in a minimum time.

The optimum keyboards of this invention are based on common linguistic and kinesthetic principles. As a result, training procedures developed for English can be applied to the foreign keyboards presented herein because they possess similar stroking patterns.

On the optimum keyboards of this invention, seven out of ten strokes occur on alternate hands, and three out of four on home keys. These repetitive patterns lead to faster responses, since it has been experimentally established that digital response times to visual stimuli are shorter for an ordered series of stimuli than for a random sequence. The regular patterns occurring in natural texts may be accentuated in instruction by employing artificial words composed of alternating vowels and consonants. These artificial words, which involves strokes on alternate hands, can exclude digraphs that rarely appear in representative prose to insure that practice exercises will be restricted to combinations that occur often in the language.

Artifical words may be arranged in rectangular arrays in which words undergo a minimum change from one word to the next in the horizontal direction, but change ina quasi-random fashion in the vertical direction. Practicing on such an array in the horizontal direction minimizes mental strain and strengthens motor reflexes, since most of the strokes are identical for successive words. Mastery of these sequences may be evaluated by comparing the time taken to input the ordered series of words in the horizontal direction with the time needed to stroke the quasi-random series in the vertical direction.

Such a rectangular array may be illustrated by the following group of twelve artifical three-letter words comprising characters stroked by the thumb, fourth, and little fingers of both hands:

| | | | |
|---|---|---|---|
| nan | ran | rin | rir |
| hir | hin | han | han |
| rar | nar | nir | nin |

This array undergoes a minimum change from one word to the next in the horizontal direction, and a quasi-random change in the vertical direction. It excludes digraphs composed of a vowel followed by an *h* because such digraphs rarely occur in English, revealing how suitable artificial words may be constructed with the aid of linguistic statistics. For actual practice, five-letter words are more effective because they approximate the mean length of words in English and offer a greater variety of stroking sequences.

A similar technique may be followed in learning the number row. Digits may be arranged in same and alternate-hand sequences, so numerical input will be mastered as a two-step process. The first step identifies a digit with a specific hand; the second with a specific finger. This two step process is feasible because the number row has been split into even and odd digits. Entering digits in pairs or triplets, rather than individually improves input accuracy because numbers are mentally encoded by operators in pairs or triplets, rather than as single digits. This procedure enables instruction on the number row to mirror training methods used for the alphabetic keys of this invention.

Table 1

Percentage of Occurrence of Space and Five Commonest Vowels in Six Languages

| | English | German | French | Italian | Spanish | Portuguese |
|---|---|---|---|---|---|---|
| 1. | — 17.6 | — 16.0 | — 17.2 | — 16.6 | — 16.7 | — 17.2 |
| 2. | e 10.3 | e 13.4 | e 11.5 | e 9.8 | e 11.7 | a 11.2 |
| 3. | o 6.3 | i 6.8 | a 7.8 | a 9.7 | a 9.8 | e 9.6 |
| 4. | a 6.6 | a 4.8 | i 7.0 | i 9.4 | o 7.4 | o 9.5 |
| 5. | i 6.0 | u 4.0 | u 5.1 | o 7.6 | i 5.2 | i 5.3 |
| 6. | u 2.2 | o 2.1 | o 4.2 | u 2.5 | u 3.5 | u 3.3 |

Table 2

Percentage of Occurrence of Five Commonest Consonants in Six Languages

| | English | German | French | Italian | Spanish | Portuguese |
|---|---|---|---|---|---|---|
| 1. | t 7.6 | n 8.8 | s 6.5 | n 5.8 | s 5.7 | s 6.3 |
| 2. | n 5.8 | r 7.0 | t 6.0 | l 5.4 | n 5.7 | r 6.0 |
| 3. | s 5.4 | s 4.7 | n 5.9 | r 5.4 | r 5.6 | n 4.6 |
| 4. | r 5.1 | t 5.3 | r 6.5 | t 5.6 | d 5.6 | d 5.0 |
| 5. | h 4.5 | h 4.0 | l 4.8 | s 4.2 | l 4.0 | t 3.8 |
| 6. | l 3.4 | d 3.5 | d 2.8 | c 3.8 | t 3.8 | m 3.6 |

Table 3

Cumulative Frequencies of Commonest Characters in Six Languages

| | English | German | French | Italian | Spanish | Portuquese |
|---|---|---|---|---|---|---|
| I | 46.8 | 45.0 | 48.6 | 53.1 | 50.8 | 52.8 |
| II | 28.4 | 30.0 | 28.6 | 25.5 | 25.7 | 24.8 |
| III | 75.2 | 75.0 | 77.2 | 78.6 | 76.5 | 77.6 |

Table 5-continued

| English Digraph Frequencies per 100,000 Letters and Spaces | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| z | 9 | 0 | 0 | 2 | 0 | 0 | 4 | 0 | 0 |
| Totals | 6,001 | 137 | 544 | 3,405 | 2,095 | 5,845 | 6,255 | 1,666 | 89 |

| First | Second r | s | t | u | v | w | x | y | z |
|---|---|---|---|---|---|---|---|---|---|
| — | 456 | 1210 | 2783 | 203 | 113 | 1068 | 1 | 149 | 4 |
| a | 692 | 608 | 927 | 73 | 137 | 44 | 14 | 170 | 11 |
| b | 74 | 24 | 9 | 142 | 4 | 0 | 0 | 100 | 0 |
| c | 93 | 12 | 247 | 82 | 0 | 0 | 0 | 21 | 0 |
| d | 65 | 79 | 1 | 79 | 11 | 5 | 0 | 40 | 0 |
| e | 1323 | 788 | 280 | 15 | 170 | 86 | 122 | 111 | 3 |
| f | 138 | 2 | 55 | 63 | 0 | 0 | 0 | 5 | 0 |
| g | 131 | 34 | 12 | 49 | 0 | 0 | 0 | 10 | 0 |
| h | 58 | 8 | 103 | 53 | 0 | 3 | 0 | 30 | 0 |
| i | 297 | 720 | 722 | 7 | 164 | 0 | 13 | 0 | 41 |
| j | 1 | 0 | 0 | 43 | 0 | 0 | 0 | 0 | 0 |
| k | 2 | 30 | 1 | 2 | 0 | 2 | 0 | 7 | 0 |
| l | 8 | 82 | 69 | 83 | 20 | 9 | 0 | 301 | 0 |
| m | 25 | 60 | 1 | 82 | 0 | 0 | 0 | 39 | 0 |
| n | 6 | 294 | 618 | 49 | 28 | 4 | 2 | 73 | 2 |
| o | 805 | 184 | 277 | 634 | 124 | 233 | 9 | 26 | 3 |
| p | 268 | 35 | 54 | 64 | 0 | 1 | 0 | 6 | 0 |
| q | 0 | 0 | 0 | 87 | 0 | 0 | 0 | 0 | 0 |
| r | 72 | 270 | 225 | 82 | 39 | 8 | 0 | 151 | 1 |
| s | 2 | 250 | 720 | 184 | 1 | 21 | 0 | 31 | 0 |
| t | 225 | 205 | 128 | 149 | 0 | 50 | 0 | 132 | 3 |
| u | 325 | 292 | 288 | 1 | 2 | 0 | 3 | 4 | 2 |
| v | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 4 | 0 |
| w | 22 | 20 | 4 | 1 | 0 | 0 | 0 | 2 | 0 |
| x | 0 | 0 | 27 | 2 | 0 | 0 | 0 | 2 | 0 |
| y | 7 | 58 | 14 | 1 | 0 | 4 | 0 | 0 | 1 |
| z | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 2 | 6 |
| Totals | 5,051 | 5,394 | 7,621 | 2,237 | 821 | 1,548 | 164 | 1,420 | 79 |

Table 6

| Percentage of One-Hand Digraphs on Ten-Finger Keyboard | Left Hand | Right Hand | Both Hands |
|---|---|---|---|
| Chords | 11.01 | 7.40 | 18.41 |
| Two Home Keys | 2.67 | 1.27 | 3.94 |
| Home & Other Key | 1.83 | 3.94 | 5.77 |
| Two Other Keys | .05 | 1.31 | 1.36 |
| Total | 15.56 | 13.92 | 29.48 |

Table 7

| One-Hand Trigraphs on Standard Keyboard per 100,000 Letters and Spaces* | | | |
|---|---|---|---|
| Frequency | No. of Trigraphs | % in Group | Cumulative % |
| 320– | 4 | 1.87 | 1.87 |
| 160–320 | 10 | 1.96 | 3.84 |
| 80–160 | 28 | 3.10 | 6.93 |
| 40–80 | 57 | 3.16 | 10.09 |
| 20–40 | 103 | 3.08 | 13.16 |
| 10–20 | 126 | 1.82 | 14.99 |

*Omits the trigraph letter-space-letter

Table 8

| One-Hand Trigraphs on the Ten-Finger Keyboard per 100,000 Letters and Spaces* | | | |
|---|---|---|---|
| Frequency | No. of Trigraphs | % in Group | Cumulative % |
| 80– | 4 | .87 | .87 |
| 40–80 | 8 | .44 | 1.21 |
| 20–40 | 12 | .36 | 1.57 |
| 10–20 | 14 | .21 | 1.78 |

*Omits the trigraph letter-space-letter

I claim:

1. An input keyboard for the transfer of information to a machine by a human operator, comprising:

a plurality of keys arranged in transversely oriented key rows as viewed by the operator: the number key row being situated at the greatest distance from the operator; the upper letter key row being situated closer to the operator than the number key row; the home key row being situated closer to the operator than the upper letter key row; the lower letter key row being situated closer to the operator than the home key row; and the thumb key row being situated closer to the operator than the lower letter key row;

wherein the upper letter key row comprises twelve keys: six keys on the left hand side of the keyboard as viewed by the operator, and six keys on the right hand side of the keyboard as viewed by the operator;

wherein the home key row comprises twelve keys: six keys on the left hand side of the keyboard as viewed by the operator, and six keys on the right hand side of the keyboard as viewed by the operator;

wherein the thumb key row comprises six keys: three keys on the left hand side of the keyboard as viewed by the operator, and three keys on the right hand side of the keyboard as viewed by the operator;

wherein the keys on the upper letter key row are designated in serial order along the upper letter key row as viewed by the operator from the outer edge of the keyboard from the center of the keyboard as follows: on the left hand side of the keyboard as viewed by the operator—the first upper letter key, the second upper letter key, the third upper letter key, the fourth upper letter key, the fifth upper letter key, and the sixth upper letter key, respectively; and on the right hand side of the keyboard as viewed by the operator—the seventh upper letter key, the eighth upper letter key, the ninth upper letter key, the tenth upper letter key, the eleventh upper letter key, and the twelfth upper letter key, respectively;

wherein the keys on the home key row are designated in serial order along the home key row as viewed by the operator from the outer edge of the keyboard to the center of the keyboard as follows: on the left hand side of the keyboard as viewed by the operator—the first home key, the second home key, the third home key, the fourth home key, the fifth home key, and the sixth home key, respectively; and on the right hand side of the keyboard as viewed by the operator—the seventh home key, the eighth home key, the ninth home key, the tenth home key, the eleventh home key, and the twelfth home key, respectively;

wherein the keys on the thumb key row are designated in serial order along the thumb key row as viewed by the operator from the outer edge of the keyboard to the center of the keyboard as follows: on the left hand side of the keyboard as viewed by the operator—the first thumb key, the second thumb key, and the third thumb key, respectively; and on the right hand side of the keyboard as viewed by the operator—the fourth thumb key, the fifth thumb key, and the sixth thumb key, respectively;

wherein the upper and lower case forms of a single letter are assigned to the same key;

wherein space and letter keys are arranged on the left hand side of the keyboard as viewed by the operator as follows: the space key, which generates the separation between words, is assigned to the second thumb key; one high frequency vowel is assigned to the second home key; a second high frequency vowel is assigned to the third home key; a third high frequency vowel is assigned to the fourth home key; and a fourth high frequency vowel is assigned to the fifth home key; wherein each of these four high frequency vowels is a different letter; and

wherein letter keys are arranged on the right hand side of the keyboard as viewed by the operator as follows: one high frequency consonant is assigned to the fifth thumb key; a second high frequency consonant is assigned to the eighth home key; a third high frequency consonant is assigned to the ninth home key; and a fourth high frequency consonant is assigned to the tenth home key; and a fifth high frequency consonant is assigned to the eleventh home key; wherein each of these five high frequency consonants is a different letter.

**2.** A keyboard, as in claim **1** for the English language comprising space and letter keys arranged as follows:

on the left hand side of the keyboard as viewed by the operator: the space key is assigned to the second thumb key, I is assigned to the second home key, O is assigned to the third home key, E is assigned to the fourth home key, and A is assigned to the fifth home key; and

on the right hand side of the keyboard as viewed by the operator: N is assigned to the fifth thumb key, R is assigned to the eighth home key, S is assigned to the ninth home key, T is assigned to the tenth home key, and H is assigned to the eleventh home key.

**3.** A keyboard, as in claim **1,** for the Italian language comprising space and letter keys arranged as follows:

on the left hand side of the keyboard as viewed by the operator: the space key is assigned to the second thumb key, O is assigned to the second home key, I is assigned to the third home key, A is assigned to the fourth home key, and E is assigned to the fifth home key; and

on the right hand side of the keyboard as viewed by the operator: N is assigned to the fifth thumb key, L is assigned to the eighth home key, S is assigned to the ninth home key, T is assigned to the tenth home key, and R is assigned to the eleventh home key.

**4.** A keyboard, as in claim **1,** for the Spanish language comprising space and letter keys arranged as follows:

on the left hand side of the keyboard as viewed by the operator: the space key is assigned to the second thumb key, O is assigned to the second home key, I is assigned to the third home key, A is assigned to the fourth home key, and E is assigned to the fifth home key; and

on the right hand side of the keyboard as viewed by the operator: R is assigned to the fifth thumb key, S assigned to to the eighth home key, T is assigned to the ninth home key, N is assigned to the tenth home key, and D is assigned to the eleventh home key.

**5.** A keyboard, as in claim **1,** for the French language comprising space and letter keys arranged as follows:

on the left hand side of the keyboard as viewed by the operator: the space key is assigned to the second thumb key, A is assigned to the second home key, I is assigned to the third home key, E is assigned to the fourth home key, and U to the fifth home key; and

on the right hand side of the keyboard as viewed by the operator: N is assigned to the fifth thumb key, S is assigned to the eighth home key, T is assigned to the ninth home key, R is assigned to the tenth home key, and L is assigned to the eleventh home key.

**6.** A keyboard, as in claim **1,** for the German language comprising space and letter keys arranged as follows:

on the left hand side of the keyboard as viewed by the operator: the space key is assigned to the second thumb key, A is assigned to the second home key, U is assigned to the third home key, E is assigned to the fourth home key, and I is assigned to the fifth home key; and

on the right hand side of the keyboard as viewed by the operator: N is assigned to the fifth thumb key, R is assigned to the eighth home key, S is assigned to the ninth home key, T is assigned to the tenth home key, and H is assigned to the eleventh home key.

**7.** A keyboard, as in claim **1,** comprising a plurality of keys:

wherein the keys as viewed by the operator are arranged in two separate groups of keys: one group of keys being situated on the left hand side of the keyboard; the other group of keys being situated on the right hand side of the keyboard; with an area in the center of the keyboard separating these two groups of keys;

wherein the keys on the number key row, the upper letter key row, and the home key row on each side of the keyboard as viewed by the operator are arranged in a curved convex arc in each key row; and these curved convex arcs on each side of the keyboard are parallel to each other;

wherein the number key row, the upper letter key row, the home key row, the lower letter key row, and the thumb key row as viewed by the operator are rotated clockwise on the left hand side of the keyboard, and are rotated counterclockwise on the right hand side of the keyboard,

wherein the key tops belonging to the second home key, the third home key, the fourth home key, the fifth home key, the eighth home key, the ninth home key, the tenth home key, and the eleventh home key are each parallel to the base of the machine to which the keyboard is attached—so that when the machine rests on a horizontal surface, each of these home key tops is horizontally oriented;

wherein the heights of the key tops belonging to the second home key, the third home key, the fourth home key, the the fifth home key, the eighth home key, the ninth home key, the tenth home key, and the eleventh home key vary to compensate for differences in finger length, so that when the height of these key tops are measured perpendicular to the plane on which the machine attached to the keyboard rests: the heights of the second home key and the eighth home key, which are equal, are tallest; the heights of the fifth home key and the eleventh home key, which are equal, are shorter than the heights of the second home key and the eighth home key; the heights of the third home key and the ninth home key, which are equal, are shorter than the heights of the fifth home key and the eleventh home key; and the heights of the fourth home key and the tenth home key, which are equal, are shorter than the heights of the third home key and the ninth home key;

wherein keys on the number key row, the upper letter key row, and the home key row are arranged so that when a plane passes through the center of the second home key, the third home key, the fourth home key, the fifth home key, the eighth home key, the ninth home key, the tenth home key, and the eleventh home key, respectively—and this plane is perpendicular to the transverse arc that passes through the center of home keys along the home key row from the outer edge of the keyboard to the center of the keyboard, this plane passes through the center of a key on the upper letter key row and through the center of a key on the number key row;

wherein the stroking surface of the first thumb key and the third thumb key each slope toward the second thumb key, so that the second thumb key rests in a trough on the left hand thumb row as viewed by the operator;

wherein the stroking surface of the fourth thumb key and the sixth thumb key each slope toward the fifth thumb key, so that the fifth thumb key rests in a trough on the right hand thumb row as viewed by the operator; and

wherein the stroking surfaces on the number key row, the upper letter key row, and the lower letter key row slope toward the home key row, so that when the heights of stroking surfaces are measured in terms of their perpendicular distance from the base of the machine to which the keyboard is attached: for individual keys on the number key row—the edge of the stroking surface that is farthest from the operator is taller than the edge of the stroking surface on the same key that is nearest to the operator; for individual keys on the upper letter key row—the edge of the stroking surface that is farthest from the operator is taller than the edge of the stroking surface on the same key that is nearest to the operator; and for individual keys on the lower letter key row—the edge of the stroking surface that is nearest to the operator is taller than the edge of the stroking surface on the same key that is farthest from the operator.



**8.** A keyboard, as in claim **2**, for the English language comprising shift and letter keys arranged as follows:

on the left hand side of the keyboard as viewed by the operator: U assigned to the first thumb key, and shift key assigned to the fourth upper letter key; and

on the right hand side of the keyboard as viewed by the operator: L assigned to the fourth thumb key, D assigned to the twelfth home key, C assigned to the ninth upper letter key, M assigned to the tenth upper letter key, and F to the eleventh upper letter key.

**9.** A keyboard, as in claim **3**, for the Italian language comprising shift and letter keys arranged as follows:

on the left hand side of the keyboard as viewed by the operator: U assigned to the first thumb key, and shift key assigned to the fourth upper letter key; and

on the right hand side of the keyboard as viewed by the operator—M assigned to the fourth thumb key, D assigned to the twelfth home key, P assigned to the ninth upper letter key, C assigned to the tenth upper letter key, and H assigned to the eleventh upper letter key.

**10.** A keyboard, as in claim **4**, for the Spanish language comprising shift and letter keys arranged as follows:

on the left hand side of the keyboard as viewed by the operator: U assigned to the first thumb key, and shift key assigned to the fourth upper letter key; and

on the right hand side of the keyboard as viewed by the operator: L assigned to the fourth thumb key, C assigned to the twelfth home key, V assigned to the ninth upper letter key, M to the tenth upper letter key, and P to the eleventh upper letter key.

**11.** A keyboard, as in claim **5**, for the French language comprising shift and letter keys arranged as follows:

on the left hand side of the keyboard as viewed by the operator: O assigned to the first thumb key, and shift key assigned to the fourth upper letter key; and

on the right hand side of the keyboard as viewed by the operator: M assigned to the fourth thumb key, D assigned to the twelfth home key, P assigned to the ninth upper letter key, C assigned to the tenth upper letter key, and H to the eleventh upper letter key.

**12.** A keyboard, as in claim **6**, for the German language comprising shift and letter keys arranged as follows:

on the left hand side of the keyboard as viewed by the operator: O assigned to the first thumb key, shift key assigned to the fourth upper letter key, and (lower case: umlaut: upper case: umlaut) assigned to the fourth upper letter key; and

on the right hand side of the keyboard as viewed by the operator: L assigned to the first thumb key, D assigned to the twelfth home key, G assigned to the ninth upper letter key, C assigned to the tenth upper letter key, and B assigned to the eleventh upper letter key.

**13.** A keyboard, as in claim **8,** for the English language comprising character and control keys arranged in serial order along key rows as viewed by the operator from the outer edge of the keyboard to the center of the keyboard as follows:

on the left hand side of the keyboard as viewed by the operator: along the thumb key row: U assigned to the first thumb key, the space assigned to the second thumb key, and the carriage return assigned to the third thumb key; along the home key row: Y assigned to the first home key, I assigned to the second home key, O assigned to the third home key; E assigned to the fourth home key, A assigned to the fifth home key, and (lower case: comma; upper case: comma) assigned to the sixth home key; along the upper letter key row: (lower case: colon: upper case: open parenthesis) assigned to the first upper letter key, (lower case: question mark; upper case; semi-colon) assigned to the second upper letter key, X assigned to the third upper letter key, the shift assigned to the fourth upper letter key, (lower case: period; upper case: period) assigned to the fifth upper letter key, and (lower case: hyphen; upper case: underline) assigned to the sixth upper letter key; on the lower letter key row: J assigned to the first lower letter key situated between the second home key and the operator, Z assigned to the second lower letter key situated between the fifth home key and the operator, and (lower case: apostrophe, upper case: exclamation point) assigned to the third lower letter key situated between the sixth home key and the operator; and on thumb keys: the shift lock assigned to the thumb key situated between the second thumb key and the operator, and the margin release assigned to the thumb key situated at the inner end of the lower letter key row in the center of the keyboard as viewed by the operator;

on the right hand side of the keyboard as viewed by the operator: along the thumb key row: L assigned to the fourth thumb key, N assigned to the fifth thumb key, and W assigned to the sixth thumb key; along the home key row: G assigned to the seventh home key, R assigned to the eighth home key; S assigned to the ninth home key; T assigned to the tenth home key, H assigned to the eleventh home key, and D assigned to the twelfth home key; along the upper letter key row: (lower case: double quotation marks; upper case: close parenthesis) assigned to the seventh upper letter key, B assigned to the eighth upper letter key, C assigned to the ninth upper letter key, M assigned to the tenth upper letter key, F assigned to the eleventh upper letter key, and K assigned to the twelfth upper letter key: along the lower letter row: V assigned to the fourth lower letter key situated between the eighth home key and the operator, P assigned to the fifth lower letter key situated between the eleventh home key and the operator, and Q assigned to the sixth lower letter key situated between the twelfth home key and the operator; and on thumb keys: the backspace assigned to the thumb key situated on between the fifth thumb key and the operator, and the tabulator assigned to the thumb key situated at the inner end of the lower letter key row in the center of the keyboard as viewed by the operator.

**14.** A keyboard, as in claim **9,** for the Italian language comprising character and control keys arranged in serial order along key rows as viewed by the operator from the outer edge of the keyboard to the center of the keyboard as follows:

on the left hand side of the keyboard as viewed by the operator: along the thumb key row: U assigned to the first thumb key, space assigned to the second thumb key, and carriage return assigned to the third thumb key; along the home key row: (lower case: accent acute; upper case: accent acute) assigned to the first home key, O assigned to the second home key, I assigned to the third home key, A assigned to the fourth home key, and E assigned to the fifth home key; and (lower case: apostrophe) assigned to the sixth home key; along the upper letter key row: (upper case: accent grave; lower case; accent grave) assigned to the third upper letter key, the shift assigned to the fourth upper letter key, and (lower case: hyphen; upper case: underline) assigned to the fifth upper letter key; and on thumb keys: the shift lock assigned to the thumb key situated between the second thumb key and the operator, and the margin release situated on the thumb key at the inner end of the lower letter key row in the center of the keyboard as viewed by the operator; and

on the right hand side of the keyboard as viewed by the operator: along the thumb key row: M assigned to the fourth thumb key, N assigned to the fifth thumb key, and F assigned to the sixth thumb key; on the home key row: B assigned to the seventh home key, L assigned to the eighth home key, S assigned to the ninth home key, T assigned to the tenth home key, R assigned to the eleventh home key; and D assigned to the twelfth home key; on the upper letter key row: (lower case: period; upper case; period) assigned to the seventh upper letter key; V assigned to the eighth upper letter key, P assigned to the ninth upper letter key, C assigned to the tenth upper letter key, H assigned to the eleventh upper letter key, and (lower case: comma; upper case: comma) assigned to the twelfth upper letter key; and on the lower letter row: Z assigned to the lower letter key situated between the eighth home key and the operator, (lower case: colon; upper case: exclamation point) assigned to the lower letter key situated between the ninth home key and the operator; (lower case: question mark; upper case: semi-colon) situated between the tenth home key and the operator, G assigned to the lower letter key situated between the eleventh home key and the operator, and Q situated between the twelfth home key and the operator; and on thumb keys: the backspace assigned to the thumb key situated between the fifth thumb key and the operator, and the tabulator assigned to the thumb key situated at the inner end of the lower letter key row in the center of the keyboard as viewed by the operator.

**15.** A keyboard, as in claim **10,** for the Spanish language comprising character and control keys arranged in serial order along key rows as viewed by the operator from the outer edge of the keyboard to the center of the keyboard as follows:

on the left hand side of the keyboard as viewed by the operator: along the thumb key row: U assigned to the first thumb key, the space assigned to the second thumb key, and the carriage return assigned to the third thumb key; along the home key row: (lower case: hyphen; upper case: underline) assigned to the first home key, O assigned to the second home key, I assigned to the third home key, A assigned to the fourth home key, E assigned to the fifth home key, and (lower case: comma; upper case; comma) assigned to the sixth home key; along the upper letter key row: X assigned to the second upper letter key, (lower case: question mark; upper case: inverted question mark) assigned to the third upper letter key, the shift assigned to the fourth upper letter key, (upper case: period; lower case: period) assigned to the fifth upper letter key, and (lower case: exclamation point; upper case: inverted exclamation point) assigned to the sixth upper letter key; along the lower letter row: (lower case: accent acute; upper case: accent acute) assigned to the lower letter key situated between fifth home key and the operator; and on thumb keys: the shift lock assigned to the thumb key situated between the second thumb key and the operator, and the margin release situated at the inner end of the lower letter key row in the center of the keyboard as viewed by the operator; and

on the right hand side of the keyboard as viewed by the operator: along the thumb key row: L assigned to the fourth thumb key row, R assigned to the fifth thumb key, and H assigned to the sixth thumb key; along the home key row: Y assigned to the seventh home key, S assigned to the eighth home key, T assigned to the ninth home key, N assigned to the tenth home key, D assigned to the eleventh home key, and C assigned to the twelfth home key; along the upper letter key row: F assigned to the eighth upper letter key, V assigned to the ninth upper letter key, M assigned to the tenth upper letter key, P assigned to the eleventh upper letter key, and Q assigned to the twelfth upper letter key; along the lower letter key row: G assigned to the lower letter key situated between the eighth home key and the operator, Z assigned to the lower letter key situated between the ninth home key and the operator, N assigned to the lower letter key situated between the tenth home key and the operator, B assigned to the lower letter key situated between the eleventh home key and the operator, and J assigned to the lower letter key situated between the twelfth home key and the operator; and on thumb keys: the backspace assigned to the thumb key situated between the fifth thumb key and the operator, and the tabulator assigned to the thumb key situated at the inner end of the lower letter key row in the center of the keyboard as viewed by the operator.

**16.** A keyboard, as in claim **11**, for the French language comprising character and control keys arranged in serial order along key rows as viewed by the operator from the outer edge of the keyboard to the center of the keyboard as follows:

on the left hand side of the keyboard as viewed by the operator: along the thumb key row: O assigned to the first thumb key, the space assigned to the second thumb key, and the carriage return assigned to the third thumb key; along the home key row: Y assigned to the first home key, A assigned to the second home key, I assigned to the third home key, E assigned to the fourth home key, U assigned to the fifth home key, and (lower case: comma; upper case comma) assigned to the sixth home key; along the upper letter key row: (lower case: circumflex; upper case circumflex) assigned to the second upper letter key, X assigned to the third upper letter key, the shift assigned to the fourth upper letter key, (lower case: period; upper case: period) assigned to the fifth upper letter key; and (lower case: hyphen; upper case: underline) assigned to the sixth upper letter key; along the lower letter row: (lower case: question mark) assigned to the lower letter key situated between the second home key and the operator, and (lower case: accent acute; upper case: accent acute) assigned to the lower letter key situated between the fifth home key and the operator; and on thumb keys, the shift lock assigned to the thumb key situated between the second thumb key and the operator, and the margin release assigned to the thumb key situated at the inner end of the lower letter key row in the center of the keyboard as viewed by the operator; and

on the right hand side of the keyboard as viewed by the operator: along the thumb key row: M assigned to the fourth thumb key, N assigned to the fifth thumb key, and F assigned to the sixth thumb key; along the home key row: G assigned to the seventh home key, S assigned to the eighth home key, T assigned to the ninth home key, R assigned to the tenth home key, L assigned to the eleventh home key, and D assigned to the twelfth home key; along the upper letter row: X assigned to the seventh upper letter key, V assigned to the eighth upper letter key, P assigned to the ninth upper letter key, and C assigned to the tenth upper letter key, H assigned to the eleventh upper letter key, and J assigned to the twelfth upper letter key, and along the lower letter key row: B assigned to the lower letter key situated between the eighth home key and the operator, and C situated between the tenth home key and the operator, Q situated between the eleventh home key and the operator, and Z situated between the twelfth home key and the operator; and on thumb keys: the backspace situated between the fifth thumb key and the operator, and the tabulator assigned to the thumb key situated at the inner end of the lower letter row in the center of the keyboard as viewed by the operator.

**17.** A keyboard, as in claim **12**, for the German language comprising character and control keys arranged in serial order along key rows as viewed by the operator from the outer edge of the keyboard to the center of the keyboard as follows:

on the left hand side of the keyboard as viewed by the operator: along the thumb key row: O assigned to the first thumb key, the space assigned to the second thumb key, and the carriage return assigned to the third thumb key; along the home row: A assigned to the second home key, U assigned to the third home key, E assigned to the fourth home key, I assigned to the fifth home key, and the shift assigned to the sixth home key; along the upper letter row: (lower case: question mark) assigned to the second upper letter key, (lower case: period; upper case: period) assigned to the third upper letter key, (lower case: umlaut; upper case: umlaut) assigned to the fourth upper letter key, (lower case: comma; upper case: comma) assigned to the the fifth upper letter key, and (lower case: hyphen; upper case: underline) assigned to the sixth upper letter key; and on thumb keys: the shift lock assigned to the thumb key situated between the second thumb key and the operator, and the margin release situated at the inner end of the lower letter key row in the center of the keyboard as viewed by the operator; and

on the right hand side of the keyboard as viewed by the operator: along the thumb key row: L assigned to the fourth thumb key, N assigned to the fifth thumb key, M assigned to the sixth thumb key; along the home key row: W assigned to the seventh home key, R assigned to the eighth home key, S assigned to the ninth home key, T assigned to the tenth home key, H assigned to the eleventh home key, and D assigned to the twelfth home key; along the upper letter key row: (lower case: $\beta$) assigned to the seventh upper letter key, F assigned to the eighth upper letter key, G assigned to the ninth upper letter key, C assigned to the tenth upper letter key, B assigned to the eleventh upper letter key, and Z assigned to the twelfth upper letter key; along the lower letter key row: V assigned to the lower letter key situated between the eighth home key and the operator, K assigned to the lower letter key situated between the eleventh home key and the operator, and P assigned to the lower letter key situated between the twelfth home key and the operator; and on thumb keys: the backspace assigned to the thumb key situated between the fifth thumb key and the operator, and the tabulator assigned to the thumb key situated at the inner end of the thumb key row in the center of the keyboard as viewed by the operator.

* * * * *