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Evaluation and Design of Alphabetic Communication Boards

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Abstract

Communication boards provide a low-cost means of facilitating communication with patients who are unable to speak; however the process is slow and frustrating. A computer model was used to calculate the cumulative frequency-weighted path length for letter selection ("chart index") for three conventional communication boards using different search strategies; and exhaustively generate and evaluate designs for a novel communication board based on a frequency-ordered arrangement of letters. For all arrangements, a 46% to 53% reduction in chart indices was achieved when "2 Dimensional" (2D) rather than "1 Dimensional" (1D) search strategies were employed. A further 23% to 30% reduction in chart indices was achieved through use of frequency-ordered sequences with optimal row groupings. Conventional communication boards can be used more efficiently by employing a 2D search strategy. Novel communication boards based on optimised arrangements of frequency-ordered letter sequences potentially provide a faster means of communication than conventional communication boards.

Keywords

Combinatorics, Compositions, Frequency Analysis, Medicine, Ergonomics

1. Introduction

Many patients on intensive care units require tracheostomy for long-term ventilatory management. During the process of weaning from mechanical ventilation, which may be prolonged, they are conscious but unable to speak. Similarly, patients with head injuries or cerebrovascular accidents may be fully conscious but unable to speak as a result of their condition. Inability to communicate can be extremely frustrating and may compromise medical care [1]. Communication boards are simple low-cost devices which allow patients to spell out words

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and phrases one letter at a time; however this process is slow.

A communication board consists of the letters of the alphabet in a given sequence, arranged into rows. An assistant points to the letters of the alphabet in turn, and the patient indicates to the assistant to stop when the desired letter is reached. Two different search strategies are employed. In a "1 Dimensional" (1D) strategy, the assistant moves their finger along each row of letters from left to right. When the end of the row is reached, they move down to the next row and continue until the patient indicates that they should stop at the indicated letter. In a "2 Dimensional" (2D) strategy, the assistant moves their finger from top to bottom, down the first letter of each row until the patient indicates that they have identified the correct row. The assistant then moves across that row from left to right until the patient indicates that they should stop at the indicated letter.

Three arrangements of letters are in common use: alphabetic order in three rows of approximately equal length; alphabetic order in five rows, broken so that each row begins with a vowel; and in the form of a three-row "QWERTY" computer keyboard (**Figure 1**).

The usability of the arrangement of letters on a communication board is a function of how frequently the letters are used, and how rapidly they may be indicated. For every chart sequence and arrangement, each letter may be assigned a "letter index" calculated as the frequency of each letter multiplied by the number of movements (individual steps down and across) required to point to that letter; with the condition that if a row contains single letter, a step down is required but no step across, since the letter may be identified by indicating the row alone. The sum of the letter indices may then be calculated to give a cumulative frequency-weighted path length or "chart index" for each arrangement of letters. A low chart index indicates an arrangement of letters which would be expected to perform more efficiently overall in practice.

Instead of arranging the letters in alphabetic- or QWERTY-order, the letters of the alphabet may be arranged in order of decreasing frequency of use, so that the most frequently used letters are reached soonest. This would be expected to decrease the time taken to spell out the majority of words, and hence decrease overall communication time. A similar technique was employed by French author Jean-Dominique Bauby, who was able to write his autobiography following a subarachnoid haemorrhage, despite being only able to blink his left eyelid [2]. Frequency distribution tables are also employed as a fundamental tool in cryptanalysis. The frequency of occurrence of letters in spoken UK English (**Table 1**) differs slightly from the frequency distribution of letters in written UK English, and therefore the former was used in this application [3].

This study evaluates the efficiency of existing sequences, arrangements, and search strategies; and proposes a novel design of frequency-ordered communication board to improve the speed and quality of communication.

2. Method

Chart indices were calculated for the three conventional communication boards (**Figure 1**) using both 1D and 2D search strategies; and were compared with the chart index obtained using a frequency-ordered list and 1D search strategy. Further analysis investigated whether it was possible to improve the chart index for a 2D search strategy of alphabetic- and frequency-ordered sequences by partitioning the sequences at optimal cutting points into a number of rows of differing lengths.

Combinatorial mathematics shows that a fixed sequence of n characters may be divided into r rows such that each row contains at least one character in:

```
ABCDEFGH        ABCD        QWERTYUIOP
IJKLMNOP        EFGH        ASDFGHJKL
QRSTUVWXYZ      IJKLMN      ZXCVBNM
                OPQRST
                UVWXYZ
```

Figure 1. Arrangement of conventional communication boards: Alphabetic, AEIOU, and QWERTY.

Table 1. Frequency distribution of letters in spoken UK English.

Letter:	E	T	A	O	I	N	S	R	H	D	L	U	C
Frequency (%):	12.02	9.10	8.12	7.68	7.31	6.95	6.28	6.02	5.92	4.32	3.98	2.88	2.71
Letter:	M	F	Y	W	G	P	B	V	K	X	Q	J	Z
Frequency (%):	2.61	2.30	2.11	2.09	2.03	1.82	1.49	1.11	0.69	0.17	0.11	0.10	0.07

$$_{(n-1)}C_{(r-1)} = \frac{(n-1)!}{(r-1)!\,((n-1)-(r-1))!}$$

different ways (*compositions*) [4] [5]. An iterative algorithm written using the open source scientific programming environment *Python* (www.python.org) was used to generate every possible composition of the alphabetic- and frequency-ordered letter sequences, partioned into 3 to 10 rows of different lengths. The chart index was calculated for each unique composition for every combination of letter sequence and number of rows, and sorted in ascending order. The lowest scoring (*i.e.* optimal) arrangement of each letter sequence was recorded in each case (**Figure 2**). The conventional charts have a fixed number of rows and characters per row by definition, and were therefore excluded from further analysis. Similarly, 1D search strategies were excluded because they would yield the same result for any given sequence regardless of the number or length of rows.

3. Results

The results for 1D and 2D search strategies using conventional communication board arrangements are shown in **Table 2**. Use of a 2D rather than 1D search strategy resulted in a 50%, 53%, and 46% reduction in chart indices respectively for the conventional alphabetic-, AEIOU-, and QWERTY-communication boards. When a 1D search strategy was used, the frequency-ordered sequence yielded a chart index of 8.563: 30% to 33% lower than that of the conventional arrangements. For a 2D search strategy, the optimal arrangements for breaking the alphabetic- and frequency-ordered sequences into different numbers of rows is shown in **Table 3**.

4. Discussion

Cheap portable computers and mobile devices provide alternatives to the traditional communication board, and offer additional features such as: gesture recognition, eye-tracking, predictive text, and dynamic frequency-based graphical interfaces [6]. However such devices are expensive, easily damaged, and may be prohibited in the critical care environment due to concerns regarding transmission of infection and radio-frequency interference with medical equipment. There is therefore still a role for low cost appropriate technologies such as the communication board.

For all three conventional chart arrangements, 2D search strategies yielded a lower chart index than 1D search strategies. The alphabetic-ordered sequences yielded slightly higher chart indices than the QWERTY-ordered sequence with 1D search strategies, but slightly lower chart indices when 2D search strategies were applied. The lowest chart index for conventional communication boards was achieved by using the alphabetic-ordered AEIOU-sequence with a 2D search strategy (**Table 2**).

```
Rows:6     Characters:26     Compositions:53130
================================================
          Arrangement                  Score
------------------------------------------------
ETAO|INSR|HDLU|CMFY|WGP|BVKXQJZ        4.628
ETAO|INSR|HDLUC|MFYW|GPB|VKXQJZ        4.635
ETAO|INSR|HDLU|CMFY|WGPB|VKXQJZ        4.636
ETAO|INSR|HDLUC|MFY|WGP|BVKXQJZ        4.639
ETAOI|NSRH|DLUC|MFYW|GPB|VKXQJZ        4.641
ETAO|INSR|HDLUC|MFYW|GP|BVKXQJZ        4.643
ETAO|INSR|HDLU|CMFYW|GPB|VKXQJZ        4.645
ETAO|INSR|HDLU|CMF|YWGP|BVKXQJZ        4.646
```

Figure 2. Sample output from software showing effect of different arrangements of line breaks (indicated by vertical bars) on chart indices (right) using a 2D search strategy.

Table 2. Chart indices for conventional communication boards, using 1D and 2D search strategies.

Search strategy	Alphabetic-ordered 3 row	Alphabetic-ordered AEIOU	QWERTY-ordered
1D	12.728	12.728	12.240
2D	6.357	6.002	6.635

Table 3. Optimal arrangements for alphabetic- and frequency-ordered sequences arranged into 3 to 10 rows using a 2D search strategy. Vertical bars indicate position of line breaks. Chart indices are given below each arrangement.

Rows	Alphabetic-ordered	Frequency-ordered	Compositions
3	ABCDEFGHIJK|LMNOPQ|RSTUVWXYZ 5.939	ETAOIN|SRHDLUC|MFYWGPBVKXQJZ 5.121	300
4	ABCDEFG|HIJKLM|NOPQR|STUVWXYZ 5.436	ETAOI|NSRHD|LUCMFY|WGPBVKXQJZ 4.798	2300
5	ABCDEFG|HIJKLM|NOPQR|STUV|WXYZ 5.303	ETAO|INSR|HDLUC|MFYW|GPBVKXQJZ 4.680	12,650
6	ABCDEFG|HIJKLM|NOPQ|RS|T|UVWXYZ 5.228	ETAO|INSR|HDLU|CMFY|WGP|BVKXQJZ 4.628	53,130
7	ABCDEFG|HIJKLM|NOPQ|RS|T|UVWX|YZ 5.162	ETAO|INSR|HDLU|CMFY|WGP|B|VKXQJZ 4.613	177,100
8	ABCDEFG|HIJKLM|NOPQ|RS|T|UVWX|Y|Z 5.140	ETAO|INSR|HDLU|CMFY|WGP|B|V|KXQJZ 4.602	480,700
9	ABCDEFG|HIJKLM|NOPQ|RS|T|U|VWX|Y|Z 5.133	ETAO|INSR|HDLU|CMFY|WGP|B|V|K|XQJZ 4.595	1,081,575
10	ABCDEFG|HIJKLM|NOPQ|RS|T|UV|W|X|Y|Z 5.139	ETAO|INSR|HDLU|CMFY|WGP|B|V|K|XQJ|Z 4.593	2,042,975

Regardless of the number of rows used, compositional analysis showed that the optimal design for both alphabetic- and frequency-ordered charts was for the letters to be arranged in rows of unequal length. For any given number of rows, the optimal frequency-ordered chart had a lower chart index than the corresponding optimal alphabetic-ordered chart. The general trend for both alphabetic- and frequency-ordered sequences was for the chart index to decrease with the number of rows from 3 to 10 rows; however the incremental reduction in chart index diminishes with each additional row (**Table 3**).

The chart index is not the only factor to be considered in the design of a novel communication board for practical use. Too many rows, or too many characters in a given row, make it more difficult to identify the chosen letter, and necessitate the use of a smaller typeface with resulting decrease in legibility. The overall design should fit comfortably within the boundaries of international standard "A-series" sheets of paper, which have proportions $1:\sqrt{2}$. The number of compositions is related to the factorial of the number of rows. The number of compositions to be tested (and hence computational time and memory requirements) therefore increases superexponentially with the number of rows. For compositions of than 10 rows, the computational demands rapidly exceed the resources of a domestic computer.

Taking the above into consideration, a six-row arrangement was deemed to be a good compromise for practical purposes. For a 2D search strategy, the optimal six-row frequency-based sequence yielded a chart index of 4.628. However, the composition with the third lowest chart index provided a more evenly balanced arrangement of characters per row, and yielded a chart index of 4.636, which was comparable to the optimal composition (**Figure 2**), and was 46% lower than the chart index for a frequency-based sequence using a 1D search strategy; 62% to 64% lower than the chart indices for conventional charts using a 1D search strategy; and 23% to 30% lower than the chart indices for conventional charts using a 2D search strategy.

A double sided communication board was designed based on the above analysis, with a frequency-ordered alphabet on one side for the patient to spell out individual words (**Figure 3**) and a table of thematically grouped common phrases on the reverse. An option on each side of the board allowed the user to indicate when to change from alphabetic spelling to phrases and vice-versa. To optimise legibility, the communication board incorporated a sans-serif typeface (*Tiresias Keyfont*) designed for visually impaired readers [7]; a colour scheme of black type on yellow background to maximise contrast; and a clear matte finish protective laminate to prevent unwanted glare and reflections [8].

This study calculates the cumulative frequency-weighted path lengths of different arrangements of letters on alphabetic communication boards; however it does not evaluate the speed and efficiency of using these different arrangements in real life. It does not take into consideration the additional time for the patient to indicate the assistant to stop twice for a 2D search strategy compared to once for a 1D search strategy. Further, it may require more cognitive effort for a patient to scan and locate their chosen letters in an unfamiliar frequency-based list compared to more familiar arrangements (alphabetic- and QWERTY-ordered lists). Thus any potential gain in

```
ETAO
INSR
HDLU
CMFY
WGPB
VKXQJZ
```

Figure 3. A practical frequency-ordered communication board (chart index: 4.636).

frequency-weighted path length may be offset by delays due to increased cognitive processing time; however a learning effect would be likely, and speed with the frequency-based chart would be expected to improve with familiarity and practice. A volunteer study is planned to evaluate the different designs in a clinical environment.

The above analysis can be readily modified and applied to other alphabets, frequency distributions, and languages. The current generation of users is familiar with using abbreviated communications in the form of mobile telephone text messages. The author is not aware of a frequency distribution table which has been compiled from analysis of text messaging, but this would have a different composition from the frequency distribution used in this study; and the design and evaluation of a communication board based on such a table would be an interesting area for further study.

The findings and methodology of this study have potential applications to other fields. For example, the graphical user interfaces of many televisions and digital video recorders require the user to incrementally move a cursor around a grid of letters when manually entering program details and titles. The grids typically use alphabetic- or QWERTY-ordered arrangements grouped into rows of equal length, and therefore do not provide optimal efficiency for data entry.

5. Conclusion

For both conventional and novel communication boards, the chart index was approximately halved when a 2D rather than a 1D search strategy was used. A further 23% to 30% reduction in cumulative frequency-weighted path lengths was achieved by adopting a frequency-ordered sequence instead of the conventional alphabet- or QWERTY-ordered sequences; and by use of an algorithm to arrange alphabetic- and frequency-ordered sequences into rows of optimal number and length. By applying these findings to the use of conventional communication boards, and to the design and use of novel communication boards, it is hoped that these measures will facilitate faster and more effective communication with patients in the critical care environment.

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