QUANTITATIVE MODELING IN AUGMENTATIVE COMMUNICATION -- A CASE STUDY

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INTRODUCTION

A general model that accounts for all the component cognitive, perceptual, and motor processes in a user's interaction with an augmentative communication system can be a powerful clinical tool. A model can provide an improved understanding of the user's performance, as well as predict the effect of changes to the system.

This paper presents one example of quantitative modeling in clinical AAC practice. A simple model for single switch letter scanning is presented. Clinical application of this model is illustrated through a case study. The patient's progress is demonstrated through actual communication rates, and these measured rates are compared to those predicted by the model.

A QUANTITATIVE MODEL

The modeling technique used can be thought of as a quantitative task analysis, in which the overall task is divided into individual steps. Time required to perform the overall task can be estimated by summing the times for each component step. The following example illustrates the technique for modeling error-free performance.

The task considered is to generate text by selecting individual characters (including "space") from a row-column scanning array. The character positions are fixed and are arranged alphabetically as shown in Fig. 1. Scanning proceeds automatically at a definable rate. The user selects the desired character by first hitting a switch when its row is scanned, then hitting the switch again when the character itself is scanned.

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A   B   C   D   E   F
G   H   I   J   K   L
M   N   O   P   Q   R   S
T   U   V   W   X   Y   Z

space
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Fig. 1. Alphabetic array for System A.

The steps required to select each character are as follows: scanning to a character's row and column and two switch hits for character selection. The total scanning time to reach a character depends on its position in the array and the system scan rate, s (1). Scanning time for an individual character, i, can be expressed as $(d_i)(s)$, where d is the distance in scan steps from the upper left hand corner. Note that $d = 0$ for the character in the upper left hand corner. The average scanning time for overall text generation is the weighted average of each character's scanning time, based on each character's relative frequency in English (1, 2). For an alphabetically arranged character array, the average scanning time can be calculated as 3.98s, where s is the scan rate.

The time required to activate the switch two times can be represented as 2h, where h is the user's switch hit time. The average overall time required to select a character from the alphabetically arranged array, then, is the sum of the average scanning time to reach the character and the switch hit time, or $T = 3.98s + 2h$, in seconds/character.

The scan rate must be set to allow time to search for the desired character, perceive when it is scanned, and hit the switch. Therefore, the switch hit time, h, must be less than the scan rate. A simplifying assumption that $h = s/2$ is made throughout this paper, because the scan rate incorporates switch hit time as well as the processes listed above.

CASE STUDY

Patient A.B. is a 64 year old woman, who is ventilator-dependent and unable to speak, secondary to Fisher variant of Guillain Barre Syndrome. Due to extensive axonal damage to the bulbar nerves, her recovery of independent speech is expected to be long term. Augmentative communication intervention was initiated in the Intensive Care Unit. A letter board was initially implemented, but it was cumbersome and resulted in limited responses. Two weeks after onset, A.B. was able to consistently protrude her mandible to operate a computer-based single switch scanning system.

There were two main criteria for the system: (1) large character display, to accomodate vision problems, and (2) simplicity, given the acute illness and difficult environment. The system chosen, referred to as System A, runs on an Apple IIc computer and employs group-item scanning. On the top level menu, it presents alphabetically arranged letter groups (A to F, G to L, etc.). When the user selects one of the groups, the screen is updated to display only the characters of the selected group. This technique is equivalent to the row-column scanning approach described above.

Over two weeks of daily practice, A.B. gradually improved to become an expert user, exhibiting very few errors. While A.B. had reached the optimum performance for her system, she did not use the system regularly because she found the text entry rate too slow. Data collection was initiated at this time, which revealed that her text entry rate was only 3.1 characters/min. It was observed that two limitations of System A contributed to the slow measured rate: (1) for each character selection, 10 seconds was required to update the display, and (2) the fastest scan rate was 1.6 sec/scan.

A modified version of the model described above was used to predict optimum rate. The 10 second display update time must be added to the basic equation derived above, so $T = 3.98s + 2h + 10$ sec/character. With a scan rate of $s = 1.6$ sec/scan, the predicted rate is 3.33 character/min. This matches the measured rate closely and yields support for the modeling approach.

Since A.B.'s scanning skills had significantly improved by this time, a more complex scanning system was introduced in response to her request for a faster system. In this system, referred to as System B, characters are arranged in a frequency-based array, so the more frequently used characters are closer to the upper left hand corner of the array. All characters are displayed simultaneously as large graphics characters in a fixed row-column arrangement, so lengthy screen updates are not necessary.

System B was modeled before A.B.'s initial trial, to predict how her performance might improve with the new system. Since the character arrangement is more efficient than System A, the average scanning time is decreased to 2.59s, where s is the scan rate. Switch hit time for each character remains 2h, where h is the time it takes for a single switch hit. There is no measurable screen update delay, which immediately saves 10 seconds per character. There are, however, two clinician-programmable delays in the system that must be incorporated into the model. The first is a pause, p, after a character is selected; this gives the user extra time to search for the next character before row scanning begins. The second is a row delay, r, after a row is selected; this gives the user extra time to select the first item in the selected row, since some users have difficulty hitting a switch quickly twice in a row. The average time per character, then, is $T = 2.59s + 2h + p + r$.

Using A.B.'s previous scan rate of 1.6 sec/scan, and assuming $h = s/2$, text generation rate for the new system was expected to be 10.4 characters/min, or three times her rate on the previous system, with no selection or row delays ($p = r = 0$). Therefore, immediate improvements in text generation rate were expected. Additionally, because System B places no limitation on the scan rate, further improvements with practice were expected.

In A.B.'s first two trials with System B, she achieved text entry rates between 6.1 and 7.8 characters/min, essentially double her previous rate. These actual rates are lower than the predicted optimal rate because selection and row delays were required to compensate for A.B's unfamiliarity with the arrangement of the character array.

Over the course of one month from the introduction of System B, the system parameters (scan rate and delays) were adjusted in response to the improvement in A.B.'s skill, resulting in a top text entry rate of 19.6 characters/min. Error-free text entry rates for each set of parameters were measured and compared to the model's prediction. These results are tabulated in Fig. 2, showing the measured rates matched the predicted rates quite closely.

Parameters (sec) s	p	r	Meas. rate (cpm)	Pred. rate (cpm)
1.44	1.0	0.0	9.7	9.7
0.96	1.36	0.36	13.9	11.6
0.6	0.6	0.1	19.6	21.0

Fig. 2. Measured vs. predicted rates for System B

DISCUSSION

The model can also be used to predict the maximum possible rate for System B. The minimum switch hit time, h, can be modeled as a simple reaction time, taking 0.2 seconds for an individual with normal cognition and motor skills (2). The minimum scan rate, s, can be set at the time it takes to perceive a character on the display and match it to an image of the desired character, plus the switch hit time. This assumes that the character positions have been memorized, so no search time is required. For an individual with normal cognition and perception, the minimum s is 0.4 sec (2). With no additional delays, the optimal rate is predicted to be 41.8 characters/minute. It should be noted that this assumes peak performance at all times, and it is not realistic to expect an individual to maintain this level of performance for long periods of time. However, it does provide an absolute maximum rate that can be used to gauge absolute progress.

Continued work with A.B. will focus on further improvement in text entry rate. Techniques such as abbreviation expansion or word prediction may be introduced in an attempt to improve text entry rate. Rate measurements will be taken to determine the effectiveness of these techniques. This will require word prediction packages that display large characters, which are currently not commercially available. In addition, a similar modeling simulation has indicated that single switch Morse code at an expert level could be faster than single switch scanning. The option of using Morse code has been discussed with A.B., but she has indicated that she is not interested in learning a brand new technique at this point.

CONCLUSIONS

Our results indicate that a simple model can be a useful predictor of communication rate. The model can be used to formulate strategies to improve performance because it reveals how each component step contributes to overall performance. Continued work to further validate the model is necessary. Finally, taking quantitative measurements of performance is by itself important because it gives an objective measure of a user's progress. Manufacturers of computer access or augmentative communication systems are urged to consider including data collection modules in their systems, to assist clinicians in this type of quantitative assessment.

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