

# **Models of Throughput Rates for Dictation and Voice Spelling for Handheld Computers**

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## **Abstract**

Since the emergence of the personal digital assistant (PDA), developers have attempted to create input methods that allow users to enter accurate data at speeds that approach those achieved with the personal computer. Common text entry methods (handwriting and soft keyboard) have input rates that are unacceptably slow for many purposes. The purpose of this paper is to consider the possible benefits of a speech-to-text input mechanism for handheld devices. By modeling throughput based on varying rates of speech, correction speeds, and system recognition accuracies, we can compare expected speech throughput rates to current throughput rates for PDAs.

## **ITIRC Keywords**

Dictation

Graffiti

Handheld

Handwriting

Modeling

PDA

Soft Keyboard

Virtual Keyboard

Speech

Voice Spelling



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## Introduction

Recent years have seen the emergence and rising popularity of handheld personal digital assistants (PDAs). These devices have many benefits, including being small, lightweight, and extremely mobile. To date, there have been two primary methods of inputting data to a PDA – tapping a small onscreen (soft) keyboard and using highly constrained handwriting recognizers such as Graffiti<sup>1</sup> or Unistrokes<sup>2</sup>. The current input speeds for these methods, however, are substantially slower than keyboard input rates achieved with a personal computer.

Virtually all users of PDAs have experience with personal computers and have some familiarity with the standard computer keyboard (the QWERTY keyboard), with which expert typists can enter data at a rates of approximately 55 words per minute (WPM; Marklin, Simoneau, & Hoffman, 1998; Norman & Fisher, 1982) with near perfect accuracy. Prior research (discussed below) has shown substantially slower rates of input for various handwriting recognizers and soft keyboards.

Hand printing speeds are typically in the 12-23 WPM range, and cursive handwriting speeds range from 16 to just over 30 WPM (Soukoreff & MacKenzie, 1995), so these, necessarily, provide estimates of the upper limits for this sort of text entry. MacKenzie and Chang (1999), using two discrete printing recognizers and a 9.5” tablet, found a mean text entry speed of 17.1 WPM. The mean recognition accuracy was 92% when the recognizer was constrained to lowercase letters and 90% when constrained to upper and lower case letters. MacKenzie and Zhang (1997), found high (95.8%) recognition accuracy for experienced users of the Graffiti handwriting recognition system, but did not report the entry speeds. Sears and Arora (2001) reported a much slower text entry rate of 4.95 WPM for the Graffiti recognizer with a recognition accuracy of 95% for participants using a PDA (rather than a tablet). They found that participants using the Jot recognizer were able to produce 7.74 WPM with an average recognition accuracy of 88%. Each of the previously mentioned studies reported rates of entry for uncorrected text. Kleid and Bonto (1995) asked users to enter a rather complex set of letters, numbers, and special characters (a person’s contact information) using Graffiti on a 6” (diagonal) screen. Participants were to attempt 100% accuracy and to use any editing tools that they felt would be helpful. They found that, under these conditions, participants were only able to enter 1.36 corrected words per minute (CWPM).

Research has shown stylus tapping on a soft QWERTY keyboard to be slightly faster than using a handwriting recognizer, but these rates are still sub-optimal. Zha and Sears (2001) reported that participants could input text on a PDA at a rate of 12.62 WPM with an average input accuracy of 96% using the soft keyboard. Using a tablet, MacKenzie, Nonnecke, McQueen, Riddersma, and Meltz (1994) found that users could type text at a rate of 22.9 WPM with 99% accuracy. MacKenzie, Zhang, and Soukoreff (1999) reported text entry rates of 20.2 WPM for participants tapping on a full-sized paper QWERTY layout. Kleid and Bonto (1995) had their participants use a soft keyboard to enter the previously described set of complex text with 100% accuracy. Under these conditions, participants were only able to obtain mean throughput rates of 3.55 CWPM.

In the past decade, users have been introduced to a new method of inputting data to a personal computer— speech dictation. While voice throughput is not yet generally as fast as typing with a full-sized QWERTY keyboard, it may offer a faster rate of throughput for handheld devices than the currently available options. Lewis (1999) defined true throughput as the number of correct words

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<sup>1</sup> Graffiti is a registered trademark of Palm Computing, Inc.

<sup>2</sup> Unistrokes is a registered trademark of Xerox Corp.

produced per minute, and found that participants could achieve rates of 31.0 CWPM with multimodal (manual and vocal) correction and 19.0 WPM with voice-only correction, using two commercially available desktop speech dictation products.

If system designers can embed voice recognition technology into the PDA environment in a way that allows users to achieve throughput rates similar to those observed by Lewis (1999), users will benefit greatly. Resource limitations of these handheld devices, however, will probably prevent the high levels of recognition accuracy reached by the desktop software. In addition, multimodal correction on a PDA will include the use of a method of input (soft keyboard or handwriting recognizer) that is less efficient than those used with the desktop systems in the Lewis study.

It is reasonable to consider the efficiency of two methods of inputting data by voice in a PDA environment: speech dictation and voice spelling. These methods can exist in isolation or in combination. To dictate, users would simply say the words they want to appear on the screen. To voice spell, the user would say codes for each letter of the alphabet. For example, rather than saying "d" the user would say, "dog." It would be possible to present a reminder display when in voice spelling mode for users who do not have the codes committed to memory.

The user would certainly be able to produce more uncorrected words per minute via dictation than by voice spelling. However, because of the limited grammar set, voice spelling would probably achieve higher levels of system recognition accuracy than dictation, reducing the need to correct. Prior modeling (Lewis, 1999) suggests that system recognition accuracy is a more important determinant of true throughput than speaking rate. Modeling true throughput (CWPM) based on input method, system accuracy, time per correction, and speaking rate can help us understand how substantial the accuracy difference between spelling and dictation (for a given speed of correction) would have to be for it to be advantageous to use the spell mode. These models would also allow comparisons of each of these speech input methods to reported throughput rates for other PDA input methods.

The aforementioned research suggests faster rates of throughput for soft keyboard input than for handwriting recognizers with a PDA. The Zha & Sears (2001) study seems to provide the best estimate of PDA throughput with a soft keyboard. These researchers used a PDA and asked participants to input a 41-word passage characteristic of a short business email message. They found a mean input rate for this task of 12.62 WPM, with a 4% error rate. Assuming a very high speed of correction, it seems reasonable to set the benchmark for the true throughput rate for soft keyboard input at 12 CWPM.

The rest of this report describes performance modeling conducted to make the following comparisons of throughput rates:

- a) dictation for the 150 WPM speaker vs. the 100 WPM speaker
- b) expert spelling for the 150 WPM speaker vs. the 100 WPM speaker
- c) novice spelling for the 150 WPM speaker vs. the 100 WPM speaker
- d) dictation vs. expert spelling for the 150 WPM speaker
- e) dictation vs. expert spelling for the 100 WPM speaker

In addition, there will be a comparison of each speech input rate to the target rate of 12 CWPM, which appears to be the best estimate of the most efficient method of text input currently available for stand-alone PDAs (not docked and connected to a personal computer).

## Method

The source text for this evaluation was a 100-word passage with 483 letters. This passage contained 101 spaces and seven punctuation marks. The passage contained no capitalization, except for characters following periods. We created six models of true throughput (using CWPM) for speech dictation and voice spelling (see Table 1). Each model contains a range of system recognition accuracies from 50% to 100% and a range of correction times from 5 to 35 seconds.

Table 1  
Description of six throughput models

Input Method	User	Speaking Rate
Dictation	All	100 WPM
		150 WPM
Voice Spelling	Novice	100 WPM
		150 WPM
	Expert	100 WPM
		150 WPM

The expert voice spelling models assumed complete automaticity in the assignment of the letters to their respective codes (in other words, users needed no processing time to match letters to their codes or to retrieve them from short term memory). The novice models assume a 230 ms eye movement time to locate each letter in the passage on the spell vocabulary reminder display. The 230 ms eye movement time is consistent with that given as the typical or “middle man” time by Card, Moran, and Newell (1983).



## The Models

### Dictation model

This model is a replication of that created by Lewis (1999), but extends the upper limit for correction times to 35 s because it is reasonable to anticipate longer correction times with a handheld device. Table 2 shows the expected throughput data (in CWPM) for a 150-WPM speaker and a 100-WPM speaker at varying levels of system recognition accuracy and varying correction speeds. The bold numbers in the table indicate the point at which speech becomes competitive with soft keyboard input for each combination of speaking rate, correction speed, and recognition accuracy (in other words, exceed 12 CWPM). Figure 1 (see Appendix A) illustrates this relationship.

Table 2  
Model of expected throughput (CWPM) rates for dictation

Speaking Rate	Correction Speed	Recognition Accuracy										
		100%	95%	90%	85%	80%	75%	70%	65%	60%	55%	50%
150 WPM	5 sec	150	92.31	66.67	52.17	42.86	36.36	31.58	27.91	25.00	22.64	<b>20.69</b>
	15 sec	150	52.17	31.58	22.64	17.65	14.46	<b>12.24</b>	10.62	9.38	8.39	7.59
	25 sec	150	36.36	20.69	<b>14.46</b>	11.11	9.02	7.59	6.56	5.77	5.15	4.65
	35 sec	150	27.91	<b>15.38</b>	10.62	8.11	6.56	5.50	4.74	4.17	3.72	3.35
100 WPM	5 sec	100	70.59	54.55	44.44	37.50	32.43	28.57	25.53	23.08	21.05	<b>19.35</b>
	15 sec	100	44.44	28.57	21.05	16.67	<b>13.79</b>	11.76	10.26	9.09	8.16	7.41
	25 sec	100	32.43	19.35	<b>13.79</b>	10.71	8.76	7.41	6.42	5.66	5.06	4.58
	35 sec	100	25.53	<b>14.63</b>	10.26	7.89	6.42	5.41	4.67	4.11	3.67	3.31

Referring to Table 2, beginning with the right hand side of the table, we can see that with a recognition accuracy of 50%, the user would need to be able to make a correction every five seconds for dictation to compete with soft keyboard input. This speed of correction seems unrealistically fast given Lewis' (1999) research, in which he found average multimodal correction speeds of 13.2 seconds per correction with desktop speech dictation systems. Given the size and processing limitations of the PDA, correction times would likely be a little slower, perhaps between 15 and 20 seconds. If we assume 15 seconds per correction, recognition accuracies as low as 70-75% would produce mean true throughput rates that are highly competitive with the target of 12 CWPM, even for a 100-WPM speaker. If correction speeds were as slow as 25 seconds per correction, a recognition accuracy of about 85% would be necessary for dictation to compete with soft keyboard input. At 35 seconds per correction, the target accuracy would be 90%.

### Expert speller model

The expert speller model allows estimation of the voice spelling throughput rates for a speaker for whom the spell letter codes have become automatic. Table 3 shows the expected spell data for an expert speller, speaking 150 WPM and 100 WPM at varying levels of recognition accuracy and varying correction speeds. The bold numbers in the table indicate the point at which speech becomes competitive with soft keyboard input. Figure 2 (see Appendix B) illustrates this relationship.

Table 3  
Model of expected throughput (CWPM) rates for the expert speller

Speaking Rate	Correction Speed	Recognition Accuracy										
		100%	95%	90%	85%	80%	75%	70%	65%	60%	55%	50%
150 WPM	5 sec	27.16	16.71	<b>12.07</b>	9.45	7.76	6.58	5.72	5.05	4.53	4.10	3.75
	15 sec	<b>27.16</b>	9.45	5.72	4.10	3.19	2.62	2.22	1.92	1.70	1.52	1.38
	25 sec	<b>27.16</b>	6.58	3.75	2.62	2.01	1.63	1.38	1.19	1.04	0.93	0.84
	35 sec	<b>27.16</b>	5.05	2.79	1.92	1.47	1.19	1.00	0.86	0.75	0.67	0.61
100 WPM	5 sec	18.10	<b>12.78</b>	9.88	8.05	6.79	5.87	5.17	4.62	4.18	3.81	3.50
	15 sec	<b>18.10</b>	8.05	5.17	3.81	3.02	2.50	2.13	1.86	1.65	1.48	1.34
	25 sec	<b>18.10</b>	5.87	3.50	2.50	1.94	1.59	1.34	1.16	1.02	0.92	0.83
	35 sec	<b>18.10</b>	4.62	2.65	1.86	1.43	1.16	0.98	0.85	0.74	0.66	0.60

This table shows that, with low levels of system recognition accuracy, voice spelling will produce unacceptably slow input rates, regardless of correction speed. Assuming a correction speed of 15 seconds, recognition accuracy would need to be greater than 95% for voice spelling to be a competitive method of inputting text.

### Novice speller model

The novice speller model allows the estimation of the throughput rates for a speaker who is just learning to use spell mode and has not yet memorized the letter codes. Table 4 shows the expected throughputs for a novice speller at 150 WPM and at 100 WPM with varying levels of system recognition accuracy and varying correction speeds. The bold numbers in the table indicate the point at which speech becomes competitive with soft keyboard input. Figure 3 (see Appendix C) illustrates this relationship.

Table 4  
Model of expected throughput (CWPM) rates for the novice speller

Speaking Rate	Correction Speed	Recognition Accuracy										
		100%	95%	90%	85%	80%	75%	70%	65%	60%	55%	50%
150 WPM	5 sec	18.47	<b>12.96</b>	9.98	8.12	6.84	5.91	5.20	4.65	4.20	3.83	3.52
	15 sec	<b>18.47</b>	8.92	5.20	3.83	3.03	2.50	2.14	1.86	1.65	1.48	1.34
	25 sec	<b>18.47</b>	5.91	3.52	2.50	1.94	1.59	1.34	1.16	1.03	0.92	0.83
	35 sec	<b>18.47</b>	4.65	2.66	1.86	1.43	1.16	0.98	0.85	0.74	0.66	0.60
100 WPM	5 sec	<b>13.79</b>	10.47	8.43	7.06	6.08	5.33	4.75	4.28	3.90	3.58	3.30
	15 sec	<b>13.79</b>	7.06	4.75	3.58	2.87	2.39	2.05	1.80	1.60	1.44	1.31
	25 sec	<b>13.79</b>	5.33	3.30	2.39	1.88	1.54	1.31	1.14	1.01	0.90	0.82
	35 sec	<b>13.79</b>	4.28	2.53	1.80	1.39	1.14	0.96	0.83	0.73	0.66	0.59

The expected novice speller data follows a pattern similar to the expert speller, but is slightly slower. Again, to be competitive, system recognition accuracy would need to be greater than 95% assuming mean correction times of 15 or more seconds.

## 150-WPM speaker model

This model provides expected throughputs for someone who speaks at a rate of 150 WPM for dictation and for expert spelling. The data enable the determination, for a given correction speed, of how much difference in recognition accuracy must exist for expert voice spelling to be more efficient than dictation. Table 5 shows the expected dictation and expert spelling throughput rates for a user who speaks at a rate of 150 WPM for varying levels of system recognition accuracy and varying correction speeds. The bold numbers in the table indicate the point at which speech becomes competitive with soft keyboard input. Figure 4 (see Appendix D) illustrates this relationship.

Table 5

Model of expected throughput (CWPM) rates for the 150-WPM speaker

Input Method	Correction Speed	Recognition Accuracy										
		100%	95%	90%	85%	80%	75%	70%	65%	60%	55%	50%
Dictation	5 sec	150.00	92.31	66.67	52.17	42.86	36.36	31.58	27.91	25.00	22.64	<b>20.69</b>
	15 sec	150.00	52.17	31.58	22.64	17.65	14.46	<b>12.24</b>	10.62	9.38	8.39	7.59
	25 sec	150.00	36.36	20.69	<b>14.46</b>	11.11	9.02	7.59	6.56	5.77	5.15	4.65
	35 sec	150.00	27.91	<b>15.38</b>	10.62	8.11	6.56	5.50	4.74	4.17	3.72	3.35
Spelling	5 sec	18.47	<b>12.96</b>	9.98	8.12	6.84	5.91	5.20	4.65	4.20	3.83	3.52
	15 sec	<b>18.47</b>	8.92	5.20	3.83	3.03	2.50	2.14	1.86	1.65	1.48	1.34
	25 sec	<b>18.47</b>	5.91	3.52	2.50	1.94	1.59	1.34	1.16	1.03	0.92	0.83
	35 sec	<b>18.47</b>	4.65	2.66	1.86	1.43	1.16	0.98	0.85	0.74	0.66	0.60

As Table 5 illustrates, given equivalent system recognition accuracy, dictation will be superior across all correction speeds, with the greatest differences coming at the higher levels of accuracy. Given the large difference in the size of the grammar sets for the two modes, however, recognition accuracy is expected to be higher when the user is in spell mode. Lewis and Commarford (2002) developed a voice spelling alphabet and tested the accuracy with a desktop system and headset microphone attachment. The grammar set (which included letter codes for voice spelling, punctuation, and cursor control commands) produced results that were 97.5% accurate under these conditions. Given that accuracy should be no higher (and might be lower) with a PDA microphone, 97.5% is an estimate of the upper limit to voice spelling accuracy. Assuming 95% accuracy for voice spelling, and 15 seconds per correction, recognition accuracy for dictation would have to be 55% or less for spelling to be a more efficient method of text input. (Under these conditions, voice spelling throughput would be 8.92 CWPM, and dictation would be 8.39 CWPM). Assuming 25 seconds per correction, dictation with recognition accuracy as low as 65% would be more efficient than voice spelling (with a voice spelling throughput of 5.91 CWPM and a dictation throughput of 6.56 CWPM). This model also indicates that unless the recognition accuracy of voice spelling is nearly perfect, it will be slower than soft keyboard input.

### 100 WPM speaker model

This model provides expected dictation and voice spelling throughput rates for an expert speller who speaks at a rate of 100 WPM. Table 6 shows the expected throughput rates. The bold numbers in the table indicate the point at which speech becomes competitive with soft keyboard input. Figure 5 (see Appendix E) illustrates the relationship.

Table 6  
Model of expected throughput (CWPM) rates for the 100-WPM speaker

Input Method	Correction Speed	Recognition Accuracy										
		100%	95%	90%	85%	80%	75%	70%	65%	60%	55%	50%
Dictation	5 sec	100.00	70.59	54.55	44.44	37.50	32.43	28.57	25.53	23.08	21.05	<b>19.35</b>
	15 sec	100.00	44.44	28.57	21.05	16.67	<b>13.79</b>	11.76	10.26	9.09	8.16	7.41
	25 sec	100.00	32.43	19.35	<b>13.79</b>	10.71	8.76	7.41	6.42	5.66	5.06	4.58
	35 sec	100.00	25.53	<b>14.63</b>	10.26	7.89	6.42	5.41	4.67	4.11	3.67	3.31
Spelling	5 sec	<b>13.79</b>	10.47	8.43	7.06	6.08	5.33	4.75	4.28	3.90	3.58	3.30
	15 sec	<b>13.79</b>	7.06	4.75	3.58	2.87	2.39	2.05	1.80	1.60	1.44	1.31
	25 sec	<b>13.79</b>	5.33	3.30	2.39	1.88	1.54	1.31	1.14	1.01	0.90	0.82
	35 sec	<b>13.79</b>	4.28	2.53	1.80	1.39	1.14	0.96	0.83	0.73	0.66	0.59

Again, the data show that, given equivalent system recognition accuracy, dictation should be superior to voice spelling across all correction speeds, with the greatest differences at the higher levels of accuracy. For the 100-WPM speaker, assuming the 15-second correction speed, dictation would be more efficient than expert spelling as long as the dictation recognition accuracy was 50% or greater (true throughput for dictation given 50% accuracy and 15 seconds per correction is 7.41 CWPM; for voice spelling given 95% accuracy and 15 seconds per correction, the true throughput is 7.06 CWPM).

## General Discussion

The purpose of creating these models was to determine the effect of system recognition accuracy, rate of speech, and speed of correction on true throughput rates for dictation and voice spelling to a PDA. Further, we sought to compare expected throughput rates for dictation, voice spelling, and soft keyboard tapping. The models demonstrate the following key findings:

1. Assuming 15 s per correction with a PDA, dictation would be as efficient as soft keyboard input as long as speech recognition accuracy were 70% or greater. Assuming dictation recognition accuracies as high as 85%-90%, dictation would be approximately twice as productive as soft keyboard entry.
2. Voice spelling will not be as efficient as soft keyboard entry unless voice spelling recognition accuracy is near perfect.
3. Voice spelling will not be as efficient as dictation unless voice spelling recognition accuracy is near perfect or dictation recognition accuracy is extremely poor.



## References

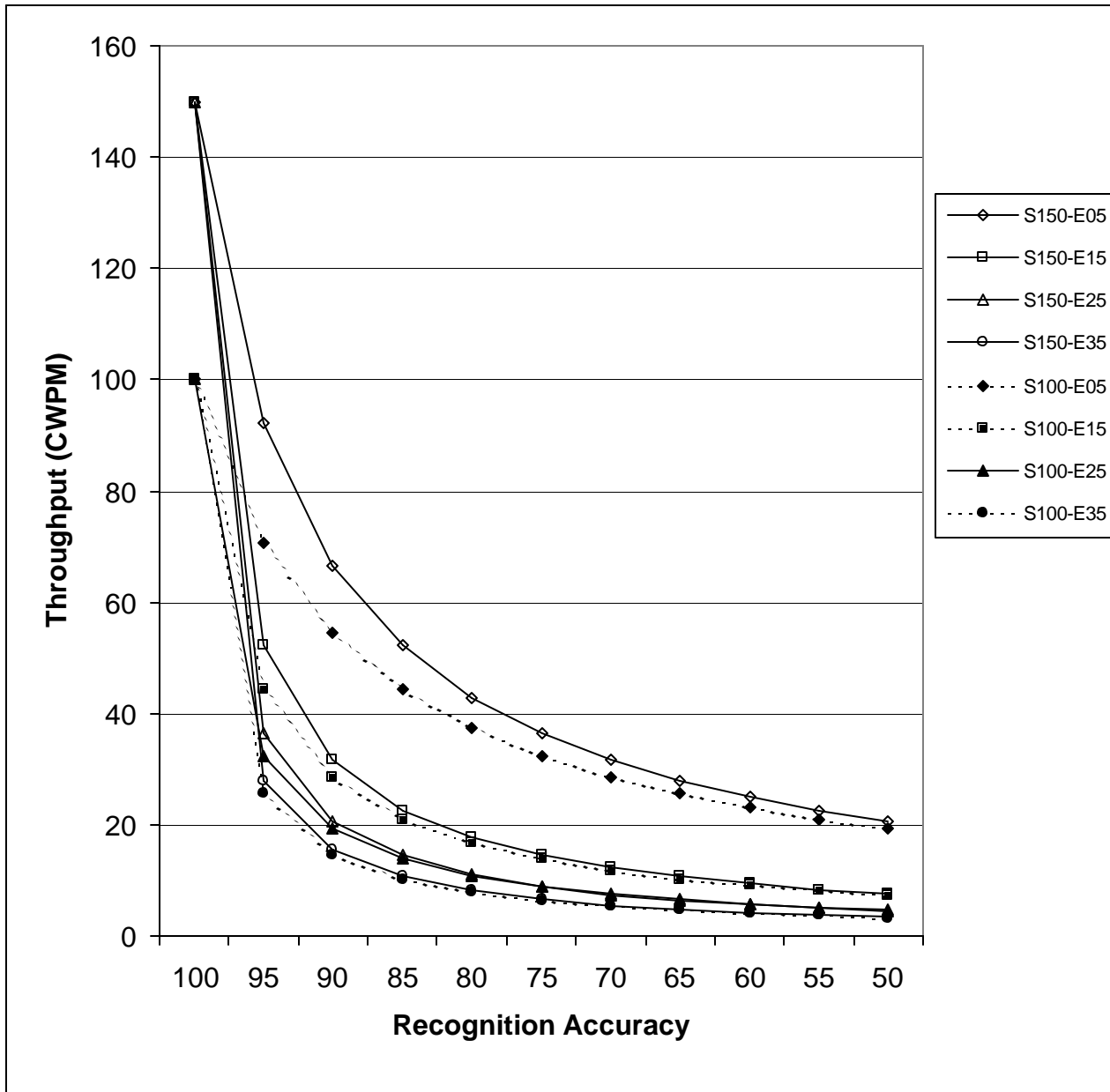
- Card, S. K., Moran, T. P., & Newell, A. (1983). *The Psychology of Human Computer Interaction*. Hillsdale, NJ: Lawrence Erlbaum.
- Kleid, N. A., & Bonto, M. A. (1995). *Handwriting recognition and soft keyboard study*. (Tech. Report 29.3008). Raleigh, NC: International Business Machines Corp.
- Lewis, J. R. (1999). Effect of error correction strategy on speech dictation throughput. In *Proceedings of the Human Factors and Ergonomics Society 43rd Annual Meeting* (pp. 457-461). Santa Monica, CA: Human Factors Society.
- Lewis, J. R. & Commarford, P. M. (2002). *Developing and tuning a voice spelling alphabet for devices with small displays*. (Tech. Report 29.3517). Raleigh, NC: International Business Machines Corp.
- MacKenzie, S. I., & Chang, L. (1999). A performance comparison of two handwriting recognizers. *Interacting with Computers, 11*, 283-297.
- MacKenzie, S. I., Nonnecke, R. B., McQueen, J. C., Riddersma, S., & Meltz, M. (1994). A comparison of three methods of character entry on pen-based computers. In *Proceedings of the Human Factors and Ergonomics Society 38th Annual Meeting* (pp. 330-334). Santa Monica, CA: Human Factors Society.
- MacKenzie, S. I., & Zhang, S. X. (1997). The immediate usability of Graffiti. In *Proceedings of Graphics Interface '97* (pp. 129-137). Toronto, Canada: Canadian Information Processing Society.
- MacKenzie, S. I., Zhang, S. X., & Soukoreff, R. W. (1999). Text entry using soft keyboards. *Behaviour and Information Technology, 18*(4), 235-244.
- Marklin, R. W., Simoneau, G. G., & Hoffman, D. (1998). Effects of computer keyboard setup parameters and user's anthropometric characteristics on wrist deviation and typing efficiency. In *Proceedings of the Human Factors and Ergonomics Society 42nd Annual Meeting* (pp. 876-880). Santa Monica, CA: Human Factors Society.
- Massaro, D. W. (1975). Perceptual images, processing time, and perceptual units in speech perception. In D. W. Massaro (ed.), *Understanding Language: An Information-Processing Analysis of Speech Perception, Reading, and Psycholinguistics* (pp. 125-150). New York, NY: Academic Press.
- Norman, D. A., & Fisher, D. (1982). Why alphabetic keyboards are not easy to use: Keyboard layout doesn't much matter. *Human Factors, 24*, 509-519.
- Sears, A., & Arora, R. (2001). An evaluation of gesture recognition for PDAs. In M. J. Smith, G. Salvendy, D. Harris, & R. J. Koubek (Eds.), *Usability Evaluation and Interface Design: Cognitive Engineering, Intelligent Agents and Virtual Reality* (pp. 1-5). Mahwah, NJ: Lawrence Erlbaum Associates.

Soukoreff, R. W., & MacKenzie, S. I. (1995). Theoretical upper and lower bounds on typing speed using a stylus and soft keyboard. *Behaviour & Information Technology*, 14(6), 370-379.

Zha, Y., & Sears, A. (2001). Data entry for mobile devices using soft keyboards: Understanding the effect of keyboard size. In M. J. Smith, G. Salvendy, D. Harris, & R. J. Koubek (Eds.), *Usability Evaluation and Interface Design: Cognitive Engineering, Intelligent Agents and Virtual Reality* (pp. 16-20). Mahwah, NJ: Lawrence Erlbaum Associates.

## Appendix A. Model of Expected Throughput Rates for Dictation

Figure 1. Model of expected throughput (CWPM) rates for dictation.

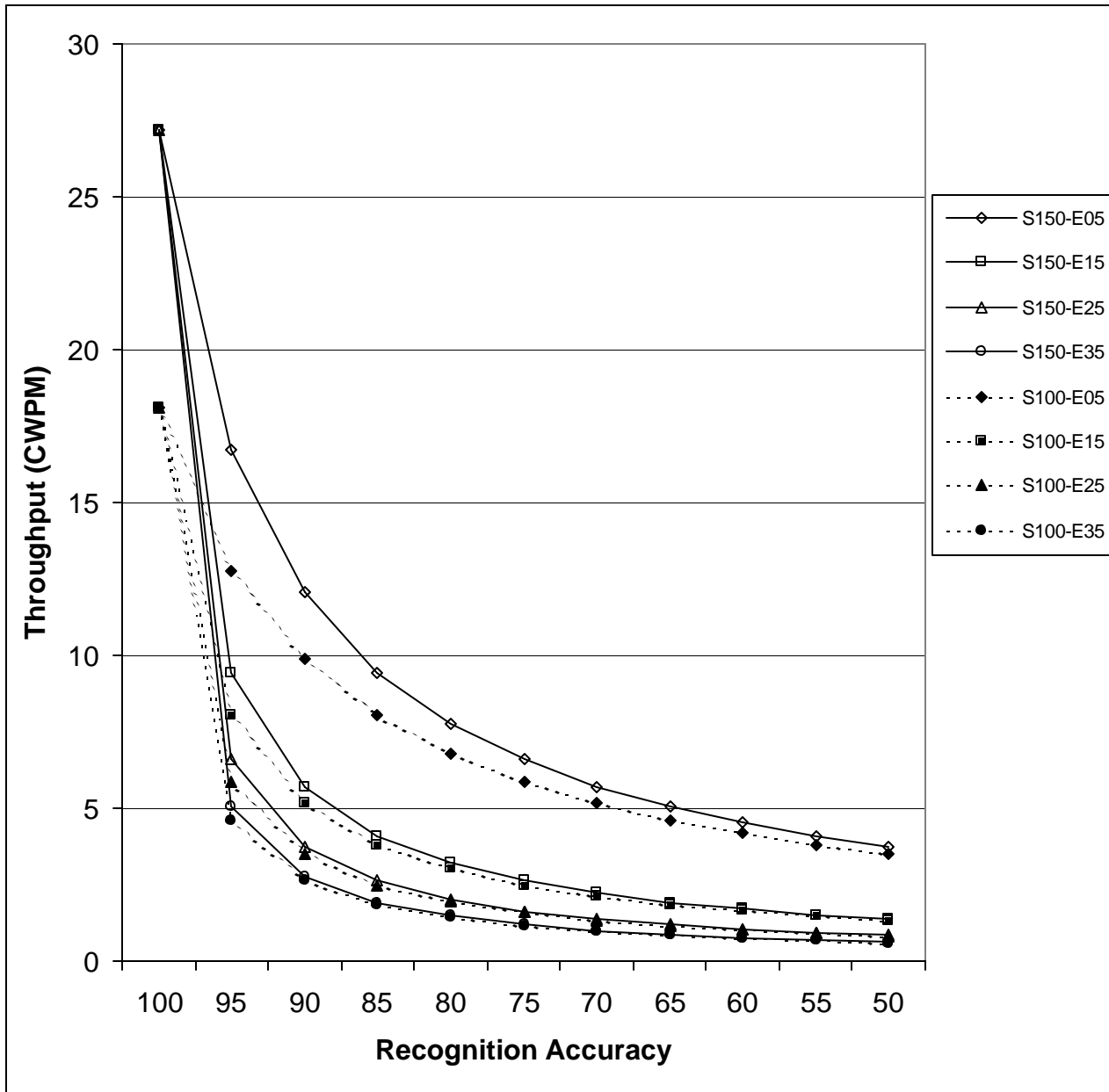


S150 = 150 WPM speaking rate  
 S100 = 100 WPM speaking rate  
 E05 = 5 seconds per correction  
 E15 = 15 seconds per correction  
 E25 = 25 seconds per correction  
 E35 = 35 seconds per correction



## Appendix B. Model of Expected Throughput (CWPM) for Expert Speller

Figure 2. Model of expected throughput (CWPM) rates for the expert speller.

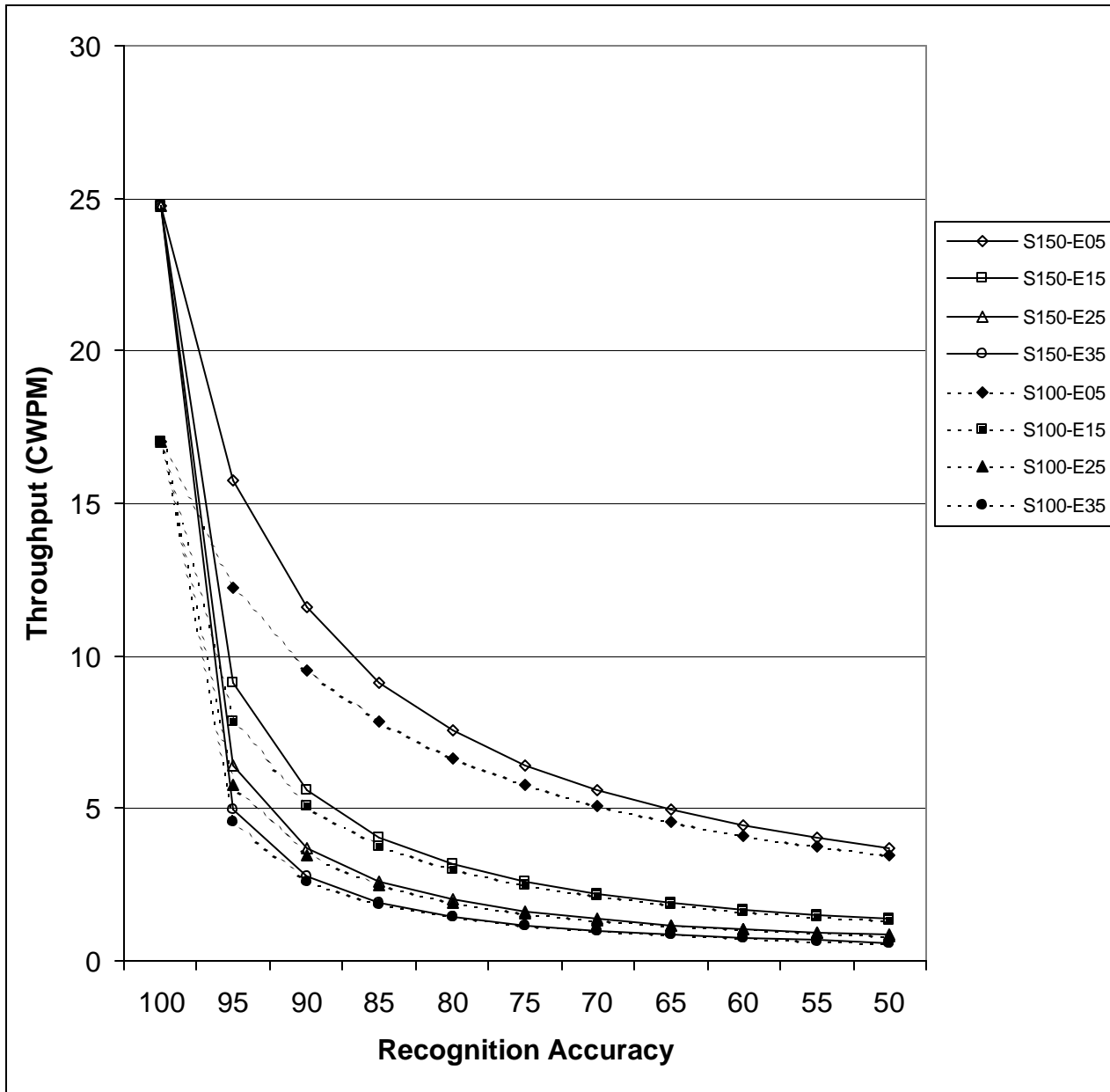


S150 = 150 WPM speaking rate  
 S100 = 100 WPM speaking rate  
 E05 = 5 seconds per correction  
 E15 = 15 seconds per correction  
 E25 = 25 seconds per correction  
 E35 = 35 seconds per correction



## Appendix C: Model of Expected Throughput (CWPM) for Novice Speller

Figure 3. Model of expected throughput (CWPM) rates for the novice speller.

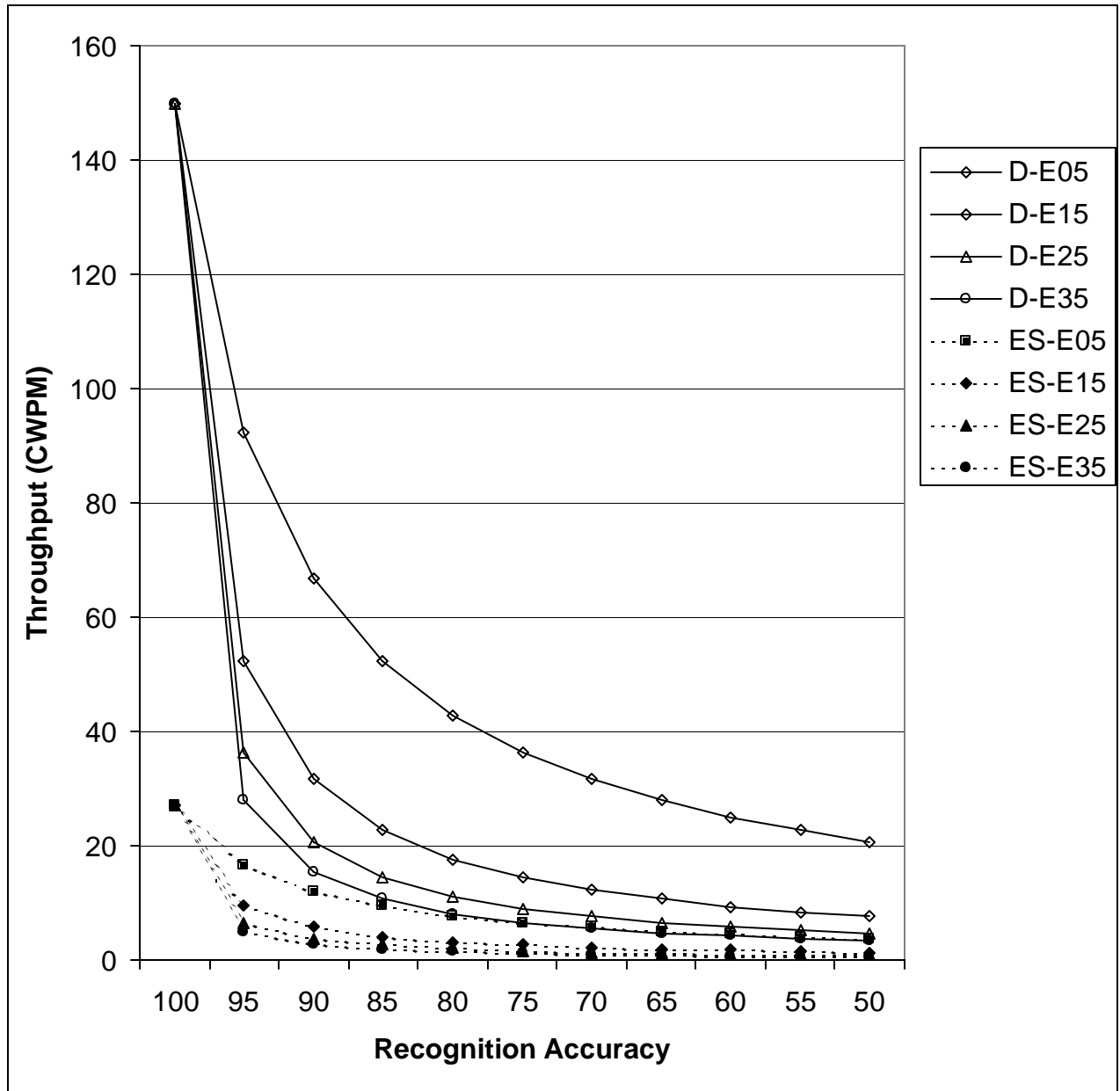


S150 = 150 WPM speaking rate  
 S100 = 100 WPM speaking rate  
 E05 = 5 seconds per correction  
 E15 = 15 seconds per correction  
 E25 = 25 seconds per correction  
 E35 = 35 seconds per correction



## Appendix D: Model of Expected Throughput (CWPM) for 150-WPM Speaker

Figure 4. Model of expected throughput (CWPM) rates for the 150 WPM speaker.

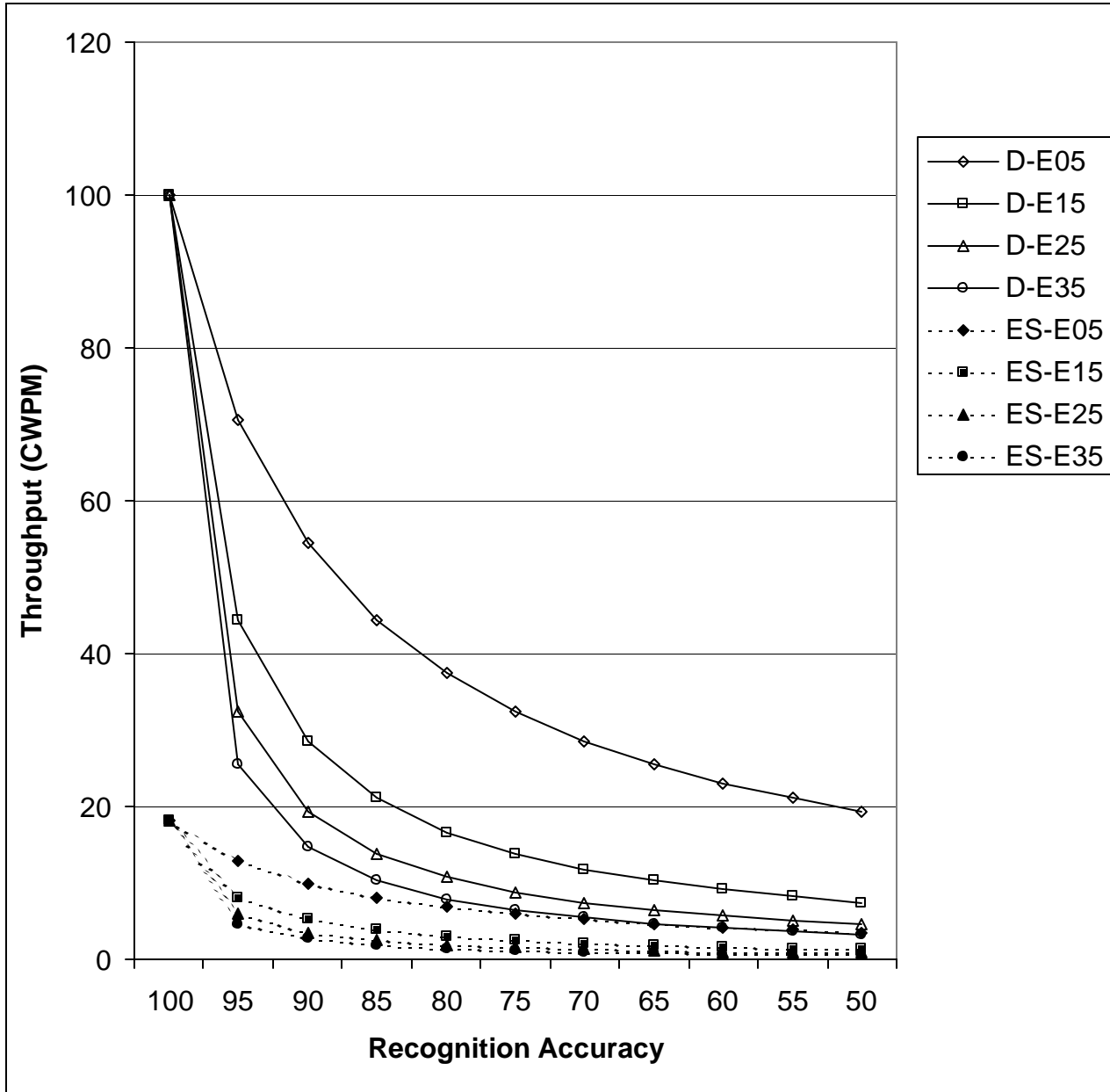


D = Dictation  
 ES = Expert Spelling  
 E05 = 5 seconds per correction  
 E15 = 15 seconds per correction  
 E25 = 25 seconds per correction  
 E35 = 35 seconds per correction



## Appendix E: Model of Expected Throughput (CWPM) for 100-WPM Speaker

Figure 5. Model of expected throughput (CWPM) rates for the 100 WPM speaker.



D = Dictation  
 ES = Expert Spelling  
 E05 = 5 seconds per correction  
 E15 = 15 seconds per correction  
 E25 = 25 seconds per correction  
 E35 = 35 seconds per correction