1B) corresponds with fusion of roughly 10^5 vesicles per cell. The use of the same two metabolic inhibitors mentioned above reduces the secretory response by more than 60 percent, thus indicating energy dependence. These points will be discussed in greater detail elsewhere.
13. B. Diamant, P. G. Kruger, B. Uvnäs, *Acta Physiol. Scand.* **79**, 1 (1970); K. Tasaka and H. Yamasaki, *Acta Derm. Venereol. Suppl.* **73**, 167 (1973).
14. B. Rose and W. R. Lowenstein, *Science* **190**, 1204 (1975).
15. W. W. Douglas and R. P. Rubin, *J. Physiol. (London)* **159**, 40 (1961); W. W. Douglas and M. Kagayama, *ibid.* **270**, 691 (1977).
16. J. C. Foreman, J. L. Mongar, B. D. Gomperts, *Nature (London)* **245**, 249 (1973); D. E. Cochrane and W. W. Douglas, *Proc. Natl. Acad. Sci. U.S.A.* **71**, 408 (1974); M. Kagayama and W. W. Douglas, *J. Cell Biol.* **62**, 519 (1974); B. Diamant and S. A. Patkar, *Int. Arch. Allergy Appl. Immunol.* **49**, 183 (1975).
17. R. Miledi, *Proc. R. Soc. London Ser. B* **183**, 421 (1973); T. Kanno, D. E. Cochrane, W. W. Douglas, *Can. J. Physiol. Pharmacol.* **51**, 1001 (1973); T. G. Hollinger and A. W. Schuetz, *J. Cell Biol.* **71**, 395 (1976).
18. Supported by PHS grant NS 09137.

21 March 1978

Writing, Dictating, and Speaking Letters

Abstract. *It is commonly assumed that dictation requires a long time to learn, but authors eventually dictate much faster than they write. Performance results now show that novice dictators can learn in a few hours to dictate with the speed and quality with which they write. However, they do not* think *they perform this well. Dictators with years of experience are from 0 to 25 percent faster than novices, depending upon the complexity of the letters. Planning time is about two-thirds of composition time, regardless of the method of composition.*

The composition of letters, memos, essays, and technical reports is widespread, time-consuming, and often difficult (*1*). Although most people write their compositions by hand, alternatives such as dictating and typewriting are used by some. Differences in the process of composition and in its resulting quality and speed made by these different methods have been speculative. We now summarize key findings from ongoing research that provide some understanding of these issues (*2*). Our experimental approach is to vary the tasks assigned to authors and the methods they are to use and to videotape them while they compose. The assigned tasks were varied by requiring each participant to compose 16 different letters. The methods they used were to write, dictate, or speak letters or to compose in "invisible writing." For invisible writing, participants wrote with a wooden stylus on paper with carbon paper underneath.

Dictating is potentially five times faster than writing, on the basis of estimates of maximum writing and speaking rates when composition is not required (*3*). Dictating may also be qualitatively superior: potentially faster transfer of ideas from limited capacity working memory to a permanent record may reduce forgetting attributable to interference or decay.

Speaking may be more "natural" than dictating because authors assume that a recipient will listen to what they say rather than read it. This allows a phraseology appropriate for listening but not necessarily for reading. Speaking may also be more natural because authors do not give typing instructions, which is a potentially disruptive secondary task.

Participants were generally college graduates, 25 to 45 years old. Eight had never dictated before. On a single day of training, they (i) learned the basic rules of dictation and how to use a dictation machine (IBM Executary) (45 minutes) and then (ii) dictated and subsequently proof-edited 16 fairly simple business letters (4 to 5 hours). They returned the next day for the experiments reported here. Eight other participants were experienced dictators, business executives who had dictated regularly for years and preferred dictating to writing. They did not go through the training day.

Each participant composed eight "routine" business letters, two each by writing, invisible writing, dictating, and speaking. These were replies to information requests. Each then composed eight more "complex," one-page letters, two each with each method. Topics included the author's feelings on capital punishment, the U.S. Bicentennial, and a letter of recommendation. The orders of the four composition methods and the eight specific letter-assignments, and the combinations of letter-assignments and methods, were counterbalanced across participants within a group with a modified 8 by 8 Greco-Latin square design.

Composition times were recorded from a participant's receipt of a letter-assignment until he or she indicated completion by stopping a clock. The videotapes were used to analyze composition times into three subtimes: pausing; generating (actual writing, dictating, or speaking); and reviewing. Written, dictated, and invisibly written letters were typed by a secretary and returned after 1 hour for participants to proof-edit. There was only one proof-editing cycle. The quality of the retyped letters was rated afterward by several independent judges on various attributes, for example, syntax and substance. Judges listened to and rated spoken letters on the same attributes (*2*).

Participants' experience, the type of letter (routine or complex), methods, and the combination of letter-assignments and methods were factors in the 2-by-2 by 4-by-2 analysis of variance for each measure, with the last three factors as the within-subjects sources of variance. Separate analyses of variance were carried out for each measure shown in Table 1.

Means for composition time and its component generation and pause times were longer for complex letters than for routine letters [F (1, 14) = 99.28, 70.84, 25.07, respectively; all $P < .001$]. In general, this was true in all methods and for both groups. Composition time depended upon method [F (3, 42) = 26.95; $P < .001$]. Speaking (6.5 minutes) was faster than dictating (7.7 minutes), and both were faster than writing (9.4 minutes) and invisible writing (8.9 minutes); Duncan's multiple range test, $P < .01$. The main reason for this was that participants' generation times were faster in dictation (3.7 minutes) and speech (3.1 minutes) than in writing (7.0 minutes) and invisible writing (6.6 minutes); Duncan's multiple range test, $P < .01$. On the other hand, pause times were longer in dictation (3.0 minutes) and speaking (2.9 minutes) than in writing (2.4 minutes) and invisible writing (2.3 minutes); Duncan's multiple range test, $P < .01$. These longer pause times in dictation and speech were caused entirely by the novice dictators [experience-by-method interaction, F (3, 42) = 9.10; $P < .001$]. Review times were brief in all methods (Table 1). They are not reported for writing because the videotapes rarely showed with certainty whether participants were reviewing. Reading time is included in pause times for all methods. Novice dictators wrote a little faster and dictated a little slower than the experienced dictators [experience-by-method interaction, F (3, 42) = 2.88; $P < .05$].

The speed advantage of speaking over dictating (6.5 versus 7.7 minutes; $P < .01$) may have arisen because composing an oral letter to be read rather than to be heard may require extra time. Alternatively, a person may just talk more slowly when the listener must type what is said.

Quality of letters, on the average, was about the same for both groups, all methods, and both types of letters. For example, on letters composed by novices,

0036-8075/78/0922-1145$00.50/0 Copyright © 1978 AAAS

rated on a 5-point scale where 1 = unacceptable, 3 = acceptable, and 5 = excellent, the scores were writing, 3.2; invisible writing, 3.1; dictating, 3.0; and speaking, 3.1 [F (3, 21), $P > .10$]. The quality of letters composed by the experienced group was similar (*2, 4*)

Does dictating take a long time to learn? Composition time for novice dictators was the same in writing and dictating (Table 1), both on routine letters [F (1, 7) = 1.39; $P > .20$] and on complex letters [F (1, 7) = 1.54; $P > .20$]. Quality scores were 3.2 and 2.9 for writing and dictating, respectively ($P > .10$), on the routine letters, and 3.2 and 3.1 ($P > .20$) on complex letters. Proof-editing changes were usually minor on both written and dictated letters.

How much faster does one become with years of practice at dictating? Those with experience dictated routine letters about 20 percent faster than the novices [but F (1, 14) = 2.48; $P > .10$], and they dictated the complex letters in the same time as the novice did. Compared with themselves, experienced dictators dictated routine letters about 35 percent faster than they wrote them and they dictated complex letters about 20 percent faster than they wrote them (Table 1). Clearly, they did not dictate five times faster than they wrote.

Writing is easier to review than dictating. Does this difference affect performance? To test this hypothesis, invisible writing was compared with writing and with dictating. For novice dictators, composition times, quality, and number of subsequent proof-editing changes (few) were the same in invisible writing (where review is impossible) as in writing and dictating [all F (2, 14); all $P > .10$]. Results were similar for experienced dictators, except that dictating was faster than writing and invisible writing on routine letters and faster than writing on complex letters (Duncan's multiple range test, $P < .05$).

The limiting factor in composition is evidently not output modality. As shown by words per minute (WPM) during generation (*5*) (Table 1), participants wrote at roughly half their maximum possible writing rate (40 WPM) and, regardless of experience, dictated at roughly one-fourth their maximum possible speaking rate (200 WPM). During generation, WPM were at least twice as great in dictating and speaking as in writing. This speed advantage had a small effect on total composition time, however, because generation time was only a small fraction of total composition time; planning time was about two-thirds of total composition time. Facial expressions, lip movements, and participants' comments indicated that planning occurred during pauses. Planning time was estimated from pause time plus a fraction of generation time, which was [generation time − (number of words/maximum possible WPM)]. The important finding that planning time is about two-thirds of composition time, regardless of method or experience, suggests that planning and generating are not independent processes. An alternative hypothesis had been that planning is independent of method of composition; that is, planning time is constant regardless of method, although it may be affected by experience. This hypothesis receives some support from the data on complex letters, where planning time was about the same for all four methods and two groups (7.1 to 8.0 minutes). On routine letters, this constant relationship did not hold, however. More generally, we doubt the validity of any simple cognitive-stage hypothesis that does not include feedback.

Novice dictators dictated about as well as they wrote. However, we hypothesized that they may not believe it. To test this, eight more participants, similar to the original novice group, were trained to dictate. The next day they rated their compositions on a 7-point scale (*4*): (i) just after composing each

Table 1. Means of measures for composing routine (R) and complex (C) letters by novice and experienced participants in writing (W), invisible writing (IW), dictating (D), and speaking (S).

Measure	Letter complexity	Novice dictators				Experienced dictators				Critical values*
		W	IW	D	S	W	IW	D	S	
Composition time (minutes)	R	6.4	6.8	5.7	3.6	7.1	7.0	4.6	3.5	1.7 to 1.9
	C	11.2	9.8	10.2	8.8	12.9	12.1	10.2	10.0	2.9 to 3.3
Generation time (minutes)	R	4.9	4.9	2.7	1.7	5.2	5.1	2.9	2.0	1.1 to 1.3
	C	8.4	7.7	3.9	3.2	9.5	8.5	5.4	5.6	2.0 to 2.3
Pause time (minutes)	R	1.5	1.7	2.1	1.7	1.8	1.9	1.4	1.3	N.S.†
	C	2.8	2.0	5.0	5.1	3.4	3.6	3.3	3.5	2.0 to 2.2
Review time (minutes)	R			0.8	0.2			0.3	0.3	
	C			1.0	0.4			1.1	0.9	
Generation periods (No.)	R	5.8	4.8	6.7	3.6	4.8	4.7	4.8	3.7	2.0 to 2.2
	C	9.2	6.3	11.6	10.0	6.9	5.8	12.0	10.6	3.3 to 3.8
Pauses (No.)	R	5.9	4.6	5.5	3.2	4.8	4.7	3.8	3.1	1.9 to 2.1
	C	9.0	6.5	10.9	9.9	6.9	5.8	8.4	7.3	3.0 to 3.5
Reviews (No.)	R			2.6	0.4			1.9	1.7	
	C			2.4	1.0			6.6	5.5	
Words (No.)	R	87.5	83.8	95.6	95.1	80.6	82.8	91.6	95.1	N.S.
	C	166	154	208	219	180	165	241	287	66 to 75
Words per minute	R	14.1	13.0	17.4	29.2	12.1	12.0	20.9	29.3	5.4 to 6.7
	C	15.1	16.3	22.5	29.3	14.3	14.5	25.2	30.5	7.4 to 8.4
Words per minute of generation time	R	18.6	17.3	36.5	61.6	16.2	16.3	33.9	49.9	9.8 to 11
	C	20.3	20.3	59.5	78.1	23.9	20.5	46.0	55.0	15 to 17
Sentence length (words)	R‡									
	C	17.9	16.5	19.2	19.4	18.1	16.7	19.3	19.7	N.S.

*Duncan's multiple range test (*9*) with $\alpha = .01$ and 98 degrees of freedom. To interpret, first rank order means within a row. The smaller critical value must be exceeded if adjacent means are to be significantly different; the larger value must be exceeded if the two extreme means are to be significantly different. Critical values for pairs of means separated by more than two but fewer than seven means can be approximated by linear interpolation. †N.S., not significant. ‡Routine letters did not lend themselves to this measure. The component times do not always sum exactly to total composition times because of rounding errors and occasional dificulty in analyzing a videotape record.

letter; (ii) about 30 to 60 minutes later, after receiving a typed version of their written or dictated letter and incorporating any proof-editing changes; and (iii) 2 weeks later. As predicted, novice dictators, just after composing, rated their two dictated letters as significantly poorer (3.8) than their two written letters (4.4) [F (1, 7) = 35.17; $P < .01$]. Subsequently they rated them as equivalent (stage 2: dictated = 4.6, written = 4.5, $P > .20$; stage 3: dictated = 4.1, written = 3.9, $P > .20$), as did outside judges (dictated = 3.6, written = 3.6). Experienced dictators, on the other hand, rated their written and dictated letters as equivalent at all stages. Written and dictated letters were similar in style. Judges performed only slightly better than chance when required to distinguish typed versions of dictated and written letters.

While dictation may fulfill some characteristics of a skill (*6*), it does not fulfill the most observable ones. Novices learned rapidly (in a few hours); problem-solving behaviors related to dictation per se were nearly absent after one training day; differences between the novice and experienced dictators were small; and differences between good and poor composers were larger than differences among composition methods. Composition, acquired with difficulty over years, appears to be the fundamental skill.

Our present understanding of composition includes more than a performance view. Performance theory (*7*) seeks to understand human behavior by identifying the skills, abilities, capacities, conditions, and cognitive mechanisms that limit and determine human behavior. This approach, while useful, is incomplete as a guide to understanding composition because it does not consider attitudes, tastes, motives, and feelings of authors. Our results suggest that both actual performance and perceived performance probably affect one's choice of method of composition in everyday life. A third class of reasons, which include secretarial variables and the sociology and organization of one's environment, need to be studied for a further understanding of compositional methods.

These results make several theoretical contributions. For example, the finding that planning time is two-thirds of composition time identifies the key process in composition, regardless of method or complexity. The conclusion that composition is the fundamental skill, and method of composition is secondary to it, contributes to the recent surge of interest in studying how experts do skilled tasks. The results demonstrate that composition can be studied successfully in the laboratory. They provide a context for investigating more specific cognitive issues in composition (*8*). At the same time, it is important to extend the present approach to longer documents, typewriting, use of computer text-editing terminals, interrupted environments (as offices are), discretionary tasks, and informal communications.

JOHN D. GOULD
STEPHEN J. BOIES
IBM Research Center, Box 218, Yorktown Heights, New York 10598

References and Notes

1. E. T. Klemmer and F. W. Snyder [*J. Commun.* **22**, 142 (1972)] reported that industrial laboratory personnel actually spend 14 percent of their day writing and believe that they spend 22 percent.
2. J. D. Gould, in *Attention and Performance*, J. Requin, Ed. (Erlbaum, Hillsdale, N.J., in press), vol. 7; *J. Exp. Psychol.*, in press; ——— and S. J. Boies, *Hum. Factors*, in press.
3. People can write memorized material or transcribe printed material as fast as 40 WPM, and they can speak memorized material or read aloud printed material as fast as 200 WPM.
4. Experienced dictators, studied several months later, were rated on a 7-point scale: 1 = unacceptable; 3 = acceptable(−); 5 = acceptable(+); and 7 = excellent. Outside judges rated written letters 4.0 and dictated ones 4.5. An interim study suggested the value of using a 7-point scale.
5. Words per minute during generation were estimated by (i) dividing total composition time into 6-second intervals, (ii) classifying a 6-second interval as generation time if a participant wrote or spoke during it, and (iii) dividing the number of words in the composition by total generation time. We are now measuring generation time to 0.1 second accuracy, which gives about the same results.
6. For discussion of skill, see F. Bartlett, *Thinking: An Experimental and Social Study* (Basic Books, New York, 19➡ D. LaBerge and S. Samuels, *Cognitive Psychol.* **6**, 293 (1974); S. Card, T. Moran, A. Newell, *Xerox Rep. SSL 76-8* (1976); G. Miller and P. Johnson-Laird, *Language and Perception* (Harvard Univ. Press, Cambridge, Mass., 1976).
7. P. M. Fitts and M. I. Posner, *Human Performance* (Brooks/Cole, Belmont, Calif., 1969).
8. See S. Rosenberg, Ed., *Sentence Production* (Erlbaum, Hillsdale, N.J., 1977), for examples of this in speech production.
9. D. B. Duncan, *Biometrics* **11**, 1 (1955).
10. We thank M. Chodorow for his helpful discussions of this work.

15 March 1978; revised 27 June 1978

Particle Capture by a Pacific Brittle Star: Experimental Test of the Aerosol Suspension Feeding Model

Abstract. Ophiopholis aculeata, *a suspension feeding brittle star, is capable of removing artificial particles from seawater by some mechanism or mechanisms other than sieving; the animal can capture a finite proportion of particles in all size classes available from at least 30 to 360 micrometers in diameter. A marked shift in the size distribution of particles caught by the animal toward larger particle sizes agrees with predictions derived from aerosol filtration theory. Adhesion of particles to the tube feet is strongly dependent on the presence of fixed charged groups on the surface of the particles.*

In most studies of suspension feeding organisms it has been implicitly or explicitly assumed that the mechanism of feeding is that of a sieve. The suspension feeding organs of these animals usually consist of a regular array of structures (such as cilia, tube feet, and tentacles), and it has been assumed that the animals capture particles passing through their filter on the basis of the relative sizes of the particles and the spaces between the filtering structures. Animals operating as a sieve should capture 100 percent of particles larger than the spaces between the filtering structures; no particles smaller than these spaces should be captured.

Rubenstein and Koehl (*1*) recently pointed out that suspension feeding animals that have some form of adhesive (typically mucus) associated with their filtering structures are analogous to man-made aerosol filters and have the potential of capturing particles by a number of nonsieving mechanisms. I report here on particle capture experiments with a suspension feeding brittle star, *Ophiopholis aculeata* (*2*). The mechanism of particle capture by the brittle star in these experiments is clearly not that of a sieve; the experimental results agree qualitatively with predictions of the aerosol suspension feeding model.

Specimens of *O. aculeata* were collected by hand from beneath cobbles in 10 to 20 m of water in the vicinity of Cantilever Pier, Friday Harbor, Washington; the animals were held in the seawater tables at Friday Harbor Laboratories with a continuous through circulation of fresh seawater. Suspension feeding experiments were conducted in a 40-liter (total volume) recirculating water tunnel (*3*); the return pipe of the water tunnel was submerged in flowing seawater to keep the tunnel at ambient seawater temperature. Given an appropriate substrate (*4*), the animals extended their arms and began suspension feeding within 15 to 30 minutes after introduction into the tunnel.

Suspension feeding in *O. aculeata* resembles the described behavior of other suspension feeding brittle stars (*5*, *6*).

0036/8075/78/0922-1147$00.50/0 Copyright © 1978 AAAS