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AND

WILLIAM FRANCIS, F.L.S.

"Nec aranearum sane textus ideo melior quia ex se fila gignunt, nec noster vilior quia ex alienis libamus ut apes." JUST. LIPS. *Polit.* lib. i. cap. 1. Not.

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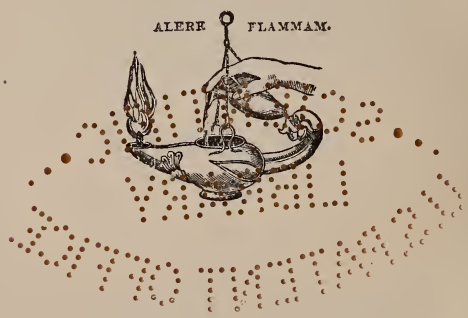
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"Meditationis est perscrutari occulta; contemplationis est admirari perspicua .... Admiratio generat quæstionem, quæstio investigationem, investigatio inventionem."—*Hugo de S. Victore.*

——"Cur spirent venti, cur terra dehiscat,
Cur mare turgescat, pelago cur tantus amaror,
Cur caput obscura Phœbus ferrugine condat,
Quid toties diros cogat flagrare cometas,
Quid pariat nubes, veniant cur fulmina cœlo,
Quo micet igne Iris, superos quis conciat orbes
Tam vario motu."

J. B. Pinelli ad Mazonium.



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ERRATUM.

Page 605, in the title to Mr. Borodowsky's paper *for* Tourjew *read* Iourjew.

the second hypothesis and those of the first, we refrain from further detail.

The second hypothesis has one advantage over the first. There is no longer the same necessity to suppose c very large compared with b. The equations resulting from c/b finite are reasonably tractable. Hence our diagram includes both saddles.

University of Tasmania,
July 5, 1909.

XII. *Telephonic Intelligibility.* *By* Geo. A. Campbell, *Ph.D.**

IN the August 1908 number (vol. xvi. p. 242) of the 'Philosophical Magazine' a paper by Lord Rayleigh contains some notes upon the acousticon, in the course of which he says:—

"The reproduction of speech, given at about one foot away from the microphone, was better than anything I had ever heard before. The first impression was that all the consonantal sounds were completely rendered, but this turned out to be an illusion. In listening to the numerals, given in order, the observer would feel confident that he heard the *f* in *five* and the *s* in *six*. But if the initial sound was prolonged —*fffive*, *ssssix*, the observer could not tell until he heard the sequel which it was going to be. Further, if the sounds were given as *ss ive*, *ff ix*, they were heard normally as five and six. It was plain that there was no difference in the rendering of *f* and *s*. I am informed that this is a well-known difficulty in ordinary telephoning, and that in spelling a name containing *f* or *s* it is usual to say '*f* for Friday' or '*s* for Saturday.' But the articulation of the acousticon is so superior that it was surprising to find the failure complete. The characterization of *sh* was not much better, though after a little practice I could distinguish it from *s* or *f*, but probably only by a greater loudness.

"These failures might have been ascribed to my rather defective hearing, but other observers with normal hearing did no better."

This statement of telephonic intelligibility is typical of the impression made by the general use of the telephone. Most of us feel that we understand almost everything transmitted by the telephone or next to nothing, according as we are listening to a familiar voice talking upon some well-known subject, or as we are obliged to listen to disconnected syllables spoken possibly in a strange tone of voice. This is obviously a case for the statistical analysis of results.

Some time ago the American Telephone and Telegraph

* Communicated by the Author.

Company began an investigation of the distortion introduced by the telephone instruments and transmission network. The work has not advanced sufficiently to warrant general statements as to the telephonic intelligibility of the 5000 phonetic syllables employed in the English language, but what has been done seems to show the order of intelligibility of the consonantal sounds with some definiteness.

For the tests which will be described the following twenty syllables, each ending in long *i* and preceded by one of the simple consonant sounds, were used:—

bi as in bee		ni as in knee	
chi	Chi(le)	pi	pea
di	de(pot), dee	ri	re(bus), rei
fi	fee	si	see
gi	Gi(zeh)	shi	she
hi	he	ti	tea
ji	gee	thi	the(ory)
ki	key	vi	ve(nus), vee
li	lee	yi	ye
mi	me	zi	ze(bra), zee.

The list contains seventeen words and three syllables which occur in compound words. According to the scientific alphabet used in the Standard Dictionary, there are but twenty-four elementary English consonant sounds. All of these consonant sounds are included except *dh*, *ng*, *w*, and *zh*; *dh* is somewhat like *th*, and was similarly recorded in an earlier series of tests; *w* was recorded correctly in 99 per cent. of the cases in a set of twelve thousand records; *ng* and *zh* are not of frequent occurrence, and do not seem to be used as syllables with merely long *i* following.

Ten lists of one hundred syllables each were prepared, every one of which contained the twenty consonants five times in a perfectly haphazard manner. All of the ten lists were spoken over the telephone connexion and a record made of the consonant heard. The tests were then continued, the experimentors changing places. All records were made in a quiet room and over quiet lines. Before this series of tests was begun the observers had made at least fifteen thousand records, and had become perfectly familiar with the method of test. The syllables were never repeated for any one given record, and the observer always made a record however uncertain he might feel as to its correctness. While the sequence of the lists and of the syllables was perfectly haphazard, the observer knew that each syllable occurred the same number of times in each list of one hundred syllables. This may have led in some cases of uncertainty to recording a syllable merely for the reason that it did not seem to have

received its proper share of records. It does not seem probable that this influenced the results to any considerable extent. As far as such an effect occurred it would correspond in a general way to the condition obtaining in the practical use of the telephone, where the subject matter and the preceding syllables give some clue as to the syllable which may be expected.

The telephonic network included regular common battery subscribers' sets at each end, common battery transformers and cord circuits at the central offices, and a line of about one hundred miles of loaded No. 16 or No. 14 B. and S. gauge cable, with the addition of from three to sixteen miles of non-loaded No. 19 B. and S. gauge cable. The series of tests over this connexion included twelve thousand records.

For comparison, tests were also made with direct transmission through the air, the same observers facing each other with no intervening obstruction but not looking at each other. The observers were fifteen feet apart in a quiet room. This series contained two thousand records.

Table I. shows the distribution of all records. Where there are two figures in a square the upper refers to the test made through the air. The syllables have been arranged in such an order as to bring those which are most frequently mistaken for each other as near together as possible. This brings the surds or voiceless consonants, *f*, *s*, *h*, *sh*, *ch*, *k*, *t*, and *p* together. The remaining consonants are all voice consonants with the exception of *th*. The occurrence of *th* among the voice consonants may be accounted for by the fact that *th* is liable to confusion with the voice consonant *dh* as in *thee*, and it is possible that in these tests the distinction between the two was not properly made. In an earlier series of tests which included *dh* in place of *th* the same mistakes were made as in the present series with *th*, that is, *dh* was confused with *v* on one side and *z* on the other. In the table the voiceless explosives *k*, *t*, and *p* come together, also the voice explosives *g*, *d*, and *b*, and the nasals *m* and *n*.

A blank square indicates that no record was made by either observer corresponding to that case. The table shows 156 such squares, and therefore of the possible incorrect cases only 59 per cent. occurred. A zero indicates that not over one-half of one per cent. of the total records for that syllable fell within that square. Had the distribution of records been entirely haphazard the average number in each square would have been 5 per cent. The table actually shows only 34 squares with 5 per cent. or more incorrect records, therefore only 9 per cent. of the incorrect cases occurred with a frequency equal to or greater than the probability corresponding to a perfectly haphazard distribution of records.

The consonants may be divided into three groups, as indicated by the heavier lines in the table, which are sufficiently distinct so that no consonant in one group is mistaken for any consonant in the other groups as frequently as 5 per cent. of the time.

The totals in the last column of Table I. show that the records were not evenly divided among the twenty syllables. Thus *knee* was recorded only 27 per cent. as many times as it was called, while *tea* was recorded nearly twice as often as called. The scattering of the records increases somewhat with the total number of records, but not proportionately.

In general each consonant was much more frequently mistaken for some one consonant than for any other. Table II. gives the correct records and the leading mistakes for transmission through the air, and in Table III. the same records are given for telephonic transmission. The last columns of these tables show that 96 per cent. of the records were correct for transmission through the air, and 59 per cent. correct for telephonic transmission. The leading mistake made for air transmission occurred in 3 per cent. of the cases (total correct and incorrect records), while for telephonic transmission the leading mistake amounted to 26 per cent. of the cases. The mistakes made through the air were also made over the telephone, but additional mistakes also occurred, and often these are the more frequent ones. The most common mistake made over the telephone was in recording *me* when *knee* was called. This occurred in 67 per cent. of the cases when *knee* was called. *Knee* is thus naturally the syllable least often recorded correctly, occurring in only 24 per cent. of the cases. *Lee* was recorded correctly in 98 per cent. of the cases, a record excelling the average for direct transmission through the air.

The records tabulated in the above tables were all made by Mr. W. L. Richards and Mr. E. C. Molina. They differed considerably in the distribution of records, but presumably the averages are about normal as far as the personal element goes. With the best possible articulation the intelligibility would undoubtedly be considerably higher.

Our tests indicate that the greater part of the distortion occurs in the subscriber's set, and that a short length of line may actually improve intelligibility as compared with zero line. As the length of line reaches the commercial limit the intelligibility gradually falls off. The tests indicate, as would be expected, that changes in the telephone apparatus and the line affect the different syllables quite differently.

It will be seen that the syllables *fee* and *see* are confused with each other in telephonic transmission. They were interchanged in 27 per cent. of the cases, and recorded correctly in 58 per cent. of the cases, which makes *f* and *s* an average pair of consonants, as the twenty consonants were

recorded correctly in 59 per cent. of the cases, and the leading mistake was made in 26 per cent. of the cases. Even as the records stand, it will be seen that *f* and *s* are correctly recorded twice as frequently as they are interchanged with each other. While these results are not directly applicable to the acousticon, which is the instrument referred to by Lord Rayleigh, the difference should be in favour of the acousticon, for our tests were made with commercial instruments over long commercial lines.

As the conditions of our tests differed from those of Lord Rayleigh in almost every particular, further tests, summarized in Table IV., have been made which bring the conditions more nearly into agreement. The number of syllables in each list was here reduced to two, and the six distinct series of tests included Lord Rayleigh's test syllables five and sive; fix and six, and also fee and see; ohm and own; am and an; me and knee. Each list contained one hundred syllables, and was varied each time it was called. The lists were called over the telephone by six persons, here designated as E, F, G, H, I, J; of these I and J were young women. Four telephone receivers were arranged in series, parallel at the receiving station, and four persons A, B, C, D, listened simultaneously and made independent records. This method materially reduced the time and labour of making this set of 14,400 records, and it also enables us to compare directly the records of different observers with any one person calling or of any one observer with different persons calling. Observer E listened directly to H, I, and J, and these records are added to the table. The ten persons who assisted in these tests were familiar with the use of the telephone, but they had had little or no practice in syllabic tests. The telephone connexion from the talking to the listening station was made through the private branch exchange of the office, and therefore the length of line included was almost negligible.

It will be seen that the records made by E for direct receiving through the air were in general nearly perfect, but that for "ohm" and "own" they were in some cases poorer than the telephonic records. Comparison of the original records for each calling of the lists shows that the distribution of mistakes was, on the whole, purely accidental, and could not be traced to definite irregularities in the pronunciation of the lists.

For Lord Rayleigh's syllables fix and six, five and sive, about 85 per cent. of the records were correct; haphazard records would have averaged but 50 per cent. correct. In one case, F calling and D recording, a perfect record was made for the "five-sive" list.

While it is obvious that the telephone seriously distorts speech-waves, nevertheless even those consonants which most nearly resemble each other are not distorted sufficiently to be indistinguishable.

TABLE I.

Distribution of Telephonic Records in Percentages
(Air Records above).

CALLED

RECORDED	*f*	*s*	*h*	*sh*	*ch*	*k*	*t*	*p*	*j*	*g*	*d*	*b*	*y*	*v*	*th*	*z*	*m*	*n*	*l*	*r*	Total.
f	97 48		20	1	5	1			1	0			1		0	0		0			77
s		100 69		28	10 17	2 3	0		2	1			2		3	1	1		0	0	160
h	0	0	99 45		8	2	0		1	1	0				0	0					58
sh	0	4	1	88 33		1				0											39
ch	1	5	9	2 35	97 41				0	5	1 0	0		0	0	0					96
k	1	0	1	0	45	100 45	4	1	3	7						1					108
t	6		2	0	5	49	98 70	15	4	11	2	1	0	0	1 1	0	0	0			197
p	2 3		1	0	1	5	1 25	100 45	0	0	3	4			0	0			0	0	87
j	0		2		1 1	0		0	87 61	12 10	0		1	0	0	2					77
g			2		0	0			13 17	87 47	1 0					0	1	0			67
d	1	0	1			0	0	4	1	23	97 91	40	1	2	3	0		0			169
b	1 1		1 1				1 0	1	0	1	2 3	99 46		4 1	1 1	0	1	1		0	58
y		0	3						2	0			98 76	0	1 0	1		1		0	84
v	2	1	1				0	1	1	0	0	1 3	1 9	90 41	8 24	7	0	0	0	0	91
th	0				1		1			0		1	1 2	6 32	88 41	15	0				93
z	1	1	2	0	0		0	0	1	0		1	4	19	25	100 72		0			127
m		0	1	0	0						0		2		0		100 90	5 67	1		162
n	0														0		3	94 24	1 0		27
l	1	0	0	0	0	0			1	0	0	0	3	1	2		5	1 6	99 98	7	125
r	0					0	0	0	1	0			1	0		0	0		1	100 92	96

TABLE II.—Air-Records.

CALLED

	f	*s*	*h*	*sh*	*ch*	*k*	*t*	*p*	*j*	*g*	*d*	*b*	*y*	*v*	*th*	*z*	*m*	*n*	*l*	*r*	Av.
Correct	97	100	99	88	97	100	98	100	87	87	97	99	98	90	88	100	100	94	99	100	96
1st incorrect ...	*p* 2		*b* 1	*s* 10	*s* 2		*b* 1		*g* 13	*j* 12	*b* 2	*v* 1	*v* 1	*th* 6	*v* 8			*m* 5	*n* 1		3
All others	1	0	0	2	1	0	1	0	0	1	1	0	1	4	4	0	0	1	0	0	1

TABLE III.—Telephonic Records.

CALLED

		f	*s*	*h*	*sh*	*ch*	*k*	*t*	*p*	*j*	*g*	*d*	*b*	*y*	*v*	*th*	*z*	*m*	*n*	*l*	*r*	Av.
Correct Records ...		48	69	45	33	41	45	70	45	61	47	91	46	76	41	41	72	90	24	98	92	59
Incorrect Records.	1st ...	*s* 34	*f* 20	*s* 28	*ch* 35	*k* 45	*t* 49	*p* 25	*t* 45	*g* 17	*d* 23	*b* 3	*d* 40	*v* 9	*th* 32	*z* 25	*th* 15	*l* 5	*m* 67	*m* 1	*l* 7	26
	2nd ...	*t* 6	*ch* 5	*ch* 9	*s* 17	*t* 5	*p* 5	*k* 4	*d* 4	*ch* 5	*t* 11	*p* 3	*p* 4	*z* 4	*z* 19	*v* 24	*v* 7	*n* 3	*l* 6	*r* 1	0	7
	3rd ...	*p* 3	*sh* 4	*y* 3	*h* 8	*s* 3	0	*th* 1	*s* 2	*t* 4	*j* 10	*t* 2	*v* 3	*l* 3	*d* 2	*d* 3	*j* 2	*b* 1	*b* 1	0	0	3
	All others	9	2	15	7	6	1	0	4	13	9	1	7	8	6	7	4	1	2	0	1	·5

TABLE IV.

Me.							Knee.					
	A	B	C	D	Av.	E	A	B	C	D	Av.	E
E	66	86	96	96	86		38	68	72	84	65	
F	80	92	70	68	77		80	88	92	68	82	
G	78	90	92	56	79		88	98	96	82	91	
H	94	96	82	90	90	100	86	98	96	92	93	100
I	52	54	54	78	59	94	50	84	76	74	71	100
J	60	88	72	84	76	90	46	72	74	64	64	98
					78						78	

Am.							An.					
	A	B	C	D	Av.	E	A	B	C	D	Av.	E
E	84	64	86	52	71		70	78	62	90	75	
F	64	76	84	78	75		64	52	50	64	57	
G	76	74	66	54	67		92	88	94	66	85	
H	90	94	88	82	88	98	90	98	98	92	94	94
I	68	62	72	74	69	96	96	94	96	96	95	84
J	80	80	64	76	75	92	90	84	84	86	86	68
					74						82	

TABLE IV. (*continued*).

	Ohm.						Own.					
	A	B	C	D	Av.	E	A	B	C	D	Av.	E
E	82	88	66	94	82		68	66	88	54	69	
F	84	86	72	86	82		90	90	92	94	91	
G	96	88	86	90	90		74	82	98	94	87	
H	94	80	82	96	88	76	96	90	94	86	91	80
I	76	82	64	76	74	72	96	88	98	88	92	82
J	80	80	68	90	79	90	94	90	92	96	93	54
					82						87	

	Fee.						See.					
	A	B	C	D	Av.	E	A	B	C	D	Av.	E
E	70	94	98	44	76		74	96	74	98	85	
F	54	90	80	40	66		74	62	96	92	81	
G	90	90	94	76	87		76	96	96	90	89	
H	68	62	76	60	66	100	82	84	90	66	80	98
I	66	70	84	70	72	100	66	44	62	66	59	100
J	66	78	88	86	79	100	68	64	60	74	66	100
					74						77	

	Fix.						Six.					
	A	B	C	D	Av.	E	A	B	C	D	Av.	E
E	92	100	92	58	86		92	84	92	78	86	
F	88	96	96	72	88		76	84	94	90	86	
G	94	96	94	78	90		86	88	98	78	87	
H	86	70	64	58	69	100	80	80	80	68	77	100
I	76	66	78	78	74	100	88	80	86	70	81	100
J	88	86	96	90	90	100	80	60	74	84	74	96
					83						82	

	Five.						Sive.					
	A	B	C	D	Av.	E	A	B	C	D	Av.	E
E	90	100	100	94	96		86	92	92	92	90	
F	100	98	100	100	99		88	100	96	100	96	
G	94	96	96	78	91		82	98	92	100	93	
H	99	100	68	78	85	100	72	80	90	96	84	98
I	60	74	90	70	73	100	64	70	82	82	74	100
J	96	86	100	94	94	100	70	60	70	96	74	98
					90						85	