ever, is a serious disadvantage of this method. The loss is aggravated by any drying method that tends to compress the plant parts or offers an absorptive surface, or both.

Our present interpretation of this artifact is as follows. When green plants are killed by quick-freezing or by other methods, all cells are killed and rendered permeable. The tracer, in solution in the original solvent or in the sap of cells that it has permeated, is free to move along any hydrostatic gradients that are set up during drying. When the tissue of quick-frozen plants is thawed, liquid moves freely but not uniformly toward drying surfaces, and the tracer is deposited in tissues en route and at the surfaces. Rapid movement most probably occurs principally in the xylem. The phloem, which normally functions in the living state, presumably could not carry on rapid transport after the tissues have been killed.

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Psychophysical Methods in the Study of Word Recognition

Two psychophysical methods have been used in the measurement of recognition thresholds for words: (i) a modified method of limits (*1*) and (ii) the method of random series (*2*). A comparison of these methods will be useful for the evaluation of past studies and may throw some light on the process of word recognition.

Twenty stimulus words, typed in capital letters on white cards, were presented in a Harvard tachistoscope. In the method of limits, a given word was exposed for increasing durations until it was recognized. Exposures were begun at 20 msec and were increased in 10-msec steps on successive trials. The order of the words was randomized. In the method of random series, all the words were first presented in a random order at 20 msec, then at 30 msec, and so on at durations increasing in 10-msec steps until all the words had been recognized. Different random orders were used for each successive series.

Table 1. Mean recognition threshold (msec).

Frequency	Method of limits					Method of random series				
	Length				Row mean	Length				Row mean
	5	7	9	11		5	7	9	11	
10	71.0	93.5	92.5	110.0	91.8	84.5	94.0	95.0	113.0	96.6
100	62.5	62.5	57.5	82.0	66.1	65.5	68.0	65.0	78.5	69.2
200	66.0	76.0	56.5	68.0	66.6	64.0	76.0	65.0	68.0	68.2
300	61.0	56.0	73.0	59.5	62.4	67.0	67.0	64.0	58.5	64.1
400	56.5	58.5	62.0	61.0	59.5	66.0	64.0	68.5	57.0	63.9
Column mean	63.4	69.3	68.3	76.1	69.3*	69.4	73.8	71.5	75.0	72.4*

* Mean threshold for all words.

The words varied with respect to length and frequency of usage. The words were five, seven, nine, and 11 letters in length. Five frequency classes were used—words occurring about 10, 100, 200, 300, and 400 times in 4.5 million according to the Thorndike-Lorge word count (*3*). Each of the 20 combinations of length and frequency was represented by one word. The stimulus words and their frequencies of occurrence per 4.5 million words were as follows. (i) Five-letter words: girth, 9; stain, 90; organ, 196; agent, 319; and shape, 405. (ii) seven-letter words: decorum, 11; tightly, 106; inspire, 196; element, 305; and weather, 391. (iii) Nine-letter words: bethought, 6; publisher, 95; household, 222; forgotten, 305; and machinery, 393. (iv) Eleven-letter words: counterpane, 7; substantial, 98; imagination, 209; possibility, 318; and association, 412.

The thresholds for the same words were measured by the method of limits in an earlier study by McGinnies, Comer, and Lacey (*4*). In the present experiment, two groups of 20 subjects were used, one of which was tested by the methods of limits, and the other by the method of random series. Subjects were assigned to the two groups at random.

The duration of exposure required for correct recognition was used as a measure of the threshold. The mean thresholds are shown in Table 1. An analysis of the variance of the threshold scores (after logarithmic transformation to remove heterogeneity of variance) is summarized in Table 2. The results obtained by the two methods are quite similar. The method of limits yields slightly lower thresholds than the method of random series. The difference between methods is, however, not significant, nor does method interact significantly with the variables of frequency and length. As measured by *both* methods, the thresholds (i) decrease with frequency of usage and (ii) increase with word length. Both these effects are significant.

There is also a significant interaction between frequency and length. Frequency has more pronounced effects with long words than with short words, and increases in length have more adverse effects on low-frequency words than on high-frequency words. These results are in agreement with the findings of McGinnies, Comer, and Lacey (*4*). Thus, speed of recognition is a joint function of frequency and length. The more favorable one of these factors is to recognition, the more limited is the range of effectiveness of the other factor. These relationships between frequency, length, and thresholds are independent of psychophysical method.

However, the method of measurement does have significant effects on the nature of subjects' responses prior to correct recognition. These responses were classified as (i) nonsense—that is, responses without dictionary meaning—and (ii) meaningful. The mean percentages per subject are shown in Table 3. The percentages of meaningful responses are virtually identical for the two groups. The method of limits results, however, in a higher percentage of nonsense responses than does the method of random series. The difference is significant at the 0.05-level by Wilcoxon's test for unpaired replicates (*5*). The method of limits favors piecemeal reconstruction of the stimulus word to a greater extent than does the method of random series. Nevertheless,

Table 2. Summary of analysis of variance of recognition scores.

Source	*df*	Mean square	*F*
Between subjects			
Methods	1	0.0798	0.36
Individuals	38	0.2226	
Within subjects			
Frequency	4	0.6983	46.24*
Length	3	0.0489	3.24†
$M \times F$	4	0.0041	0.27
$M \times L$	3	0.0125	0.83
$F \times L$	12	0.0612	4.05*
Pooled error‡	734	0.0151	

* Significant beyond the 0.01 level. † Significant beyond the 0.05 level. ‡ The interaction $M \times F \times L$ was not significant and was pooled with the residual.

Table 3. Mean percentages of trials per subject on which nonsense and meaningful prerecognition responses were given.

Responses	Method			
	Limits		Random series	
	Mean	S.D.*	Mean	S.D.
Nonsense	25.3	10.8	19.3	6.8
Meaningful	10.1	6.7	10.2	4.1

* S.D., standard deviation.

the frequency of meaningful prerecognition responses and the speed of recognition are similar for the two methods.

Meaningful responses, including incorrect guesses and correct recognitions, depend on the discrimination of stimulus fragments which enable the subject to attempt a reconstruction of the stimulus word. It appears that successive exposures of the same word do not substantially accelerate the discrimination of minimally effective stimulus fragments. At the very least, the influence of cumulative presentations is masked by the effects of exposure duration as such.

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1. For illustrations of this method, see D. H. Howes and R. L. Solomon, *J. Exptl. Psychol.* **41**, 401 (1951); R. L. Solomon and L. Postman, *J. Exptl. Psychol.* **43**, 195 (1952).
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Mechanism of Freezing in (Plant or Animal?) Living Cells and Tissues

The recent paper by Meryman (*1*) includes a treatment of the physical principles of ice-crystal growth that fills a real need for all biologists. But his treatment of "Freezing in cellular biological systems" almost completely ignores the vast amount of work that has been done on plants (*2*). As a result, much of what he says certainly does not hold true for plant cells. The following are a few cases in point:

1) "The lethal factor . . . is the exceedingly high concentration of electrolyte resulting from the removal of water. . . ." This theory was proposed 50 years ago to explain frost injury to plants. Some 6 years later it was completely disproved by Maximov, who showed that cells that are normally killed at −5°C survive −20°C if they are frozen in nonpenetrating and nontoxic solutions. Many other lines of evidence oppose the theory in the case of plant cells (*2*).

2) "If the specimen survives this far [−10°C], further decrease in temperature causes no further change in the degree of dehydration. . . ." Direct measurements by Scholander and coworkers (*2*) have shown continuous and progressive increases in ice formation both in animal and plant tissues down to about −30°C.

3) "Whether this [intracellular freezing of dead cells] is simply a reflection of loss of viability and membrane permeability . . . has not been experimentally investigated." It has been experimentally investigated by several workers, including Chambers and Hale, whom Meryman cited. The evidence indicates that membrane permeability is the cause of the intracellular freezing.

4) "It is nevertheless a fact that crystallization is wholly or predominantly extracellular until rather rapid rates of freezing are obtained. . . ." The speed of freezing that results in the formation of intracellular ice varies markedly among plants, particularly when hardy and nonhardy plants are compared. To define rapid and slow freezing on the basis of the rate needed to induce intra- or extracellular freezing (as Meryman does) would imply that rapid freezing in some plants is slower than slow freezing in others.

5) "In addition to the lethal potential of intracellular crystal growth, rapid freezing also creates a dehydration with the same potential for denaturation. . . ." Injury from intracellular freezing occurs at much higher temperatures (and therefore milder dehydrations) in hardy plants than does injury from extracellular freezing. Furthermore, in nearly all cases among the vast number that have been reported, intracellular freezing injury has occurred practically instantaneously. Extracellular freezing injury, on the other hand, as well as other kinds of dehydration injury (for example, plasmolysis injury) increases with the time of exposure to it (*2*). Finally, no plant cells have yet been discovered that are able to survive intraprotoplasmic freezing at moderate temperatures, although some are able to survive much greater dehydration than others. Consequently, dehydration can play no part in the injury produced.

6) "The rapidity with which destructive ice crystals can grow in the solid state renders the thawing procedure equally, if not more, demanding than the freezing procedure." This may be true of the extremely rapid and intense freezing that occurs when small pieces of tissue are plunged into liquid air, but it does not apply to more moderate freezing (for example, at −10°C) that is still rapid enough to produce intracellular ice formation in plant cells. In such cases (see previous paragraphs) the cells are always killed, regardless of the speed or nature of the thawing process.

7) "The addition of glycerine . . . limits the degree of dehydration produced." It is very easy to show that this is not true in the case of plant cells (*2*). When glycerine is allowed to penetrate the cells, the best that can be obtained is an ability to withstand temperatures 2 or 3 degrees lower. When the cells are frozen immediately in the glycerine solution before appreciable penetration has occurred (or in other solutions that do not penetrate) they can be made to survive a temperature 15°C lower. Yet the dehydration in the latter case is much greater.

There are perhaps three main reasons for expecting differences in the freezing behavior of plant cells and of the kind of animal cells that Meryman is mostly concerned with: (i) the (mainly cellulose) cell wall surrounding plant cells, (ii) the bathing fluid around the animal cells, and (iii) the large vacuole in each mature cell, at least of higher plants. Whether or not there are really major differences between the mechanisms of freezing in plant and animal cells, I do not know. But it seems obvious that a better understanding of the latter would be sure to result from better acquaintance with the work on plants (and vice versa). I would therefore like to suggest a greater exchange of reprints between the animal and plant scientists in this field as well as in others.

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Levitt's observation that the article, "Mechanics of freezing in living cells and tissues," is primarily concerned with animal material is quite correct, and possibly the title should have so indicated. However, although it would, in retrospect, have been advisable to include more allusions to plant material, detailed discussions of freezing in specific tissues was, as stated in the introduction, not the