Centruroides suffusus (Mexican) venom reacted with a precipitin produced to other species native to Brazil, South Africa, and Algeria. Venom of the Turkish scorpion, *Androctonus australis*, shares common antigen-antibody reactions with antisera produced in Brazil, South Africa, and Algeria; several *Centruroides spp.* venoms from Mexico also share one or more precipitins with immune sera made in Brazil, South Africa, and Algeria. The antivenins were prepared to the scorpion genus of greatest medical importance in each area. For the purposes of this study intrageneric relationships were not determined.

Extracts of a dried telson of *Androctonus crassicauda* and three post-abdominal segments from the same animal were prepared by trituration in saline followed by centrifugation at 4°C (1000*g*, 30 min). The solutions were then used for fractional absorption of *Androctonus* antivenin (Algeria) at three antigen concentrations. Absorbed antivenins were reacted in double diffusion columns for 91 hours (30° ± .01°C) versus telsons. Of the four precipitin systems in the telson series, two were absorbed with the post-abdominal segment extract. The possibility exists, therefore, that the desiccated solutions used for the immunization of the horses contained post-abdominal segment substance(s), or that such substance(s) or similar ones also occur in the telson.

The complexity of homologous scorpion venom-antivenin reactions was such that some systems, namely, *Parabuthis spp.* venom (10 mg/ml) showed as many as seven precipitin zones at one antiserum concentration when reacted for 68 hours at 30° ± .01°C. There were no homologous reactions that showed fewer than two antigen-antibody systems.

From these results, assuming that the major toxic components of the venoms were reflected in the precipitating systems, the possibility exists that an appropriate combination of certain immune horse sera would be the most feasible approach toward the preparation of a polyvalent antivenin for the genera considered (*16*).

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6. *Androctonus australis.*
7. *Centruroides vittatus* (Camp Bullis, Texas); *C. suffusus* (Durango, Mexico); *C. sculpturatus* (Superior, Arizona); *C. noxius* (Tepic, Nayarit State, Mexico); *C. elegans* (San Blas, Nayarit, Mexico); and *C. limpidus tecomanus* (Manzanillo, Colima State, Mexico).
8. Sôro Anti-escorpionico, "Butanan" from horses immunized with *T. bahiensis* and *T. serrulatus* venom.
9. Serum Antiscorpionique, Institut Pasteur d'Algérie.
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16. Most of the venoms and antivenins utilized in this study were supplied through the generosity of the following scientists: Dr. N. Erzin, Central Institute of Hygiene, Ankara, Turkey; Dr. L. Balozet, Institut Pasteur d'Algérie, Algiers; Dr. Flavio da Fonseca and Dr. Wolfgang Bücherl, Instituto Butantan, São Paulo, Brazil; and Dr. J. D. Mason, South African Institute for Medical Research, Johannesburg, South Africa. Mexican antivenin was purchased and species of genus *Centruroides* from Mexico and the United States were collected by two of us (H.L.K. and F.W.W.) with funds provided for Research and Development Project No. 6X61-13-001, Research and Development Command, Office of the Surgeon General, Department of the Army.

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Collection and Washout of Airborne Pollens and Spores by Raindrops

Abstract. Data on aerodynamic capture of particles are used to estimate efficiency of collection of pollen grains and spores by falling raindrops. Simple probability arguments then yield the fractional removal of airborne pollens and spores by rain. Pollen grains are generally large enough to be washed out by all but the lightest showers of large thunderstorm-type drops; smaller-sized spores experience lower removal rates. Various specialists concerned with pollen dissemination will find rain-scavenging a significant process.

Whether an airborne pollen grain of density ρ and diameter d (typically of the order of a few tens of microns) will be swept out by an approaching raindrop of diameter D (typically of the order of tenths of a millimeter to a few millimeters) falling with velocity V in air of absolute viscosity μ is dependent upon the magnitude of the dimensionless inertial parameter K given (*1*) by

$$K = (\rho d^2 V)/(9\,\mu D) \qquad (1)$$

It will be acceptable to ignore the terminal velocity of the pollen grain, since it is of the order of only a few percent of V. If K is large, the pollen grain will not easily be pushed aside by the pressure field set up ahead of the falling raindrop, and the probability of collection will be enhanced. The collection efficiency E (defined here as the fraction of all pollen grains lying in the cylindrical region of diameter D swept out by the raindrop which are actually hit by the drop) is, as a result of the recent computer studies, a now-known function (*1–3*) of K and of the Reynolds number at which the raindrop falls. I have here used E values of Fonda and Herne (see *3*), probably the best data now available, interpolating between the viscous and aerodynamic flow regimes after the manner indicated by Langmuir (*1*). Pollen grains may be treated as point-centers in calculating E, with only negligible error because their finite size alters E only for the smallest drizzle drops where removal efficiency is nearly complete anyhow. Values of V and associated Reynolds numbers were taken from the work of Gunn and Kinzer (see *4*). Adequate indication of trends can be displayed by giving results only for raindrop diameters of 0.2, 1.0, and 4.0 mm. A diameter of 0.2 mm is the meteorologically accepted dividing point between large cloud drops and small drizzle drops; 1.0 mm is representative of the bulk of raindrops in most rainfalls; 4.0 mm is near the upper limit of drop diameters occurring in thunderstorm rainfall.

Data on ρ and d for pollen grains were taken from Erdtman (*5*), and data for some spores were taken from Maunsell (*6*). It should be stressed that all one actually needs here is the product, ρd^2. Inspection of Stokes' law for spheres falling at terminal velocity reveals that this product may be computed directly from the pollen or spore terminal velocity, an approach that is actually preferable to separate microscopic measurement of d and pycnometric estimation of ρ inasmuch as any intrinsic departures from Stokes' law (due, say, to grain asphericity or surface roughness) will be automatically incorporated into the ρd^2 product derived from terminal velocity observations, improving precision of estimation of E. The air bladders of pine and certain other conifers depart from the spherical model underlying Stokes' law, but experience with other aspherical particle problems suggests that this will not be serious. Whether every col-

Table 1. Collection efficiencies (E) and washout probabilities (P_R) for some pollens and spores, for raindrops of diameters (D) indicated (in mm) and rainfalls (R) as indicated.

ρ (g/cm³)	d (μ)	E (percent)			P_R (percent)					
					R = 0.1 cm			R = 1.0 cm		
		D 0.2	D 1.0	D 4.0	D 0.2	D 1.0	D 4.0	D 0.2	D 1.0	D 4.0
Picea excelsa pollen										
0.55	63	91	97	96	99	77	30	99	99	98
Ambrosia elatior pollen										
1.1	20	71	87	84	99	73	27	99	99	96
Juniperus communis pollen										
0.41	26	65	84	78	99	72	25	99	99	80
Mucor racemosus spores										
1	7	1	45	30	7	49	11	53	99	68
Penicillium spinulosum spores										
1	3.5	0	7	2	0	10	1	0	65	7

lision between a raindrop and a pollen grain or spore leads to capture (rather than bounce-off) is unknown; but again, experience gained from other capture problems indicates probably high coalescence efficiency here, so complete absence of bounce-off will be assumed.

Calculated values of collection efficiency E for the three raindrop sizes as they affect three pollen types and two spore types are shown in Table 1. In all cases, E is somewhat greater for $D = 1.0$ mm than for the smaller or the larger drop diameter, a trend familiar in raindrop collection aerodynamics when the size of collected particles is small enough compared to that of the drops. Note that *Penicillium* spores are collected with only very small efficiency by typical raindrops or thunderstorm drops and not at all by small drizzle drops. This is because of their comparatively low inertia; such small spores are very readily swept around the raindrop.

To estimate the degree of washout of pollen or spores, we may consider rains composed of a *single* drop size. More realistic models are not too difficult to handle, as has been shown by Greenfield (*7*) for the case of precipitation-scavenging of radioactive debris, but present purposes will be quite adequately met by considering only monodisperse rains.

Let the effective capture cross-section of a given raindrop for a specified pollen grain of diameter d, namely $E\pi D^2/4$, be rendered dimensionless by division by unit area (1 cm^2), the quotient being identified as q. If a vertical column of 1 cm^2 horizontal cross section contains pollen particles at randomly located positions, the probability that any one grain will be *missed* by descent of one raindrop falling somewhere within the column is $1 - q$; and the probability that the grain will be missed by *all* of n successive drops is $P_n = (1 - q)^n$. Taking the natural logarithm of both sides, expanding the right side in a series, using the fact that $q \ll 1$, and converting to exponential form, yields $P_n = e^{-nq}$, to a high degree of approximation. But $n = 6R/\pi D^3$, where R is the depth of rainfall as conventionally measured (here also interpretable dimensionally as the volume of rain precipitated on unit ground-area), and by definition $q = E\pi D^2/4$, so we may write for the probable fraction *removed* from a large sample of grains initially present in our column

$$P_{\mathrm{R}} = 1 - e^{-(3RE/2D)} \qquad (2)$$

after fall of R cm of rain of drop diameter D and collection efficiency E for the pollen grains or spores in question.

In the two right-hand sections of Table 1 are shown values of P_R computed from Eq. 2 and expressed as percentages, for two values of R. The value $R = 0.1$ cm represents a very light shower, while $R = 1$ cm is a rather more representative amount for individual rains in most regions of the world. The latter rain, regardless of prevailing drop-size, will almost completely scavenge pollen from the subcloud layer. A light shower of the order $R = 0.1$ cm yields essentially complete washout only if the bulk of the drop sizes are small, of the order of drizzle diameters, but even for the commonly observed D of 1 mm, about three-fourths of the pollens are removed by a mere 0.1 cm of rain. A passing flurry of *large* drops, say from the edge of a thunderstorm ($R = 0.1$ cm, $D = 4.0$ mm), leaves two-thirds to three-fourths of the pollen grains airborne because of the lower E of such large drops and because the total geometric cross section of large drops is small for given R.

Rates of removal of small particles run generally much lower, and exhibit much wider variations, as can be seen from the last two rows of values of P_R. *Penicillium* spores are scarcely affected, except for moderate rain with drop diameters peaked near 1.0 mm, and the *Mucor* spores behave in intermediate fashion.

Palynologists and allergists may benefit by the now readily available data on collection efficiency, of the type here discussed. Failure to take due account of the frequently very efficient washout of pollens or spores by rain could produce serious error in estimates of the atmospheric budgets of these particles, as in paleoecologic studies. The role of rainfall in alleviating, at least temporarily, allergic response to widespread airborne pollens, such as *Ambrosia* (ragweed), undoubtedly deserves further attention from allergists.

Ecologists and forest management workers should examine the possibility that poor pollination years for a given species in a given area may be significantly influenced by a chance sequence of rains, especially frequent, intermittent, light rains of small drop-size (Table 1). Correlation between protracted raininess and deficient pollination has been noted (*8*), but apparently not attributed to raindrop scavenging. Scavenging after emission may be as important as, or perhaps in some instances more important than, rainfall-induced closing of anthers or direct mechanical washoff of pollen in forestalling emission. Indeed, the typical requirement of warm, dry weather for emission may be a selective adaptation, minimizing the adverse role of raindrop scavenging, above all in cases where longer-range dispersal has value for species survival (*9*).

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Stabilization of Behavior and Prolonged Exposure to Delayed Auditory Feedback

Abstract. The disruption of fluent verbal behavior found under delayed feedback is replaced by stable patterns when presentation is prolonged. Experimental analysis suggests that the later patterns involve the reinstatement of control by stimuli in whose presence the behavior was originally established.

The auditory or visual stimuli produced by speaking or writing need not occur immediately, as is normally the case, but may be presented to a subject after a brief delay. The reported result is a disruption of behavior (*1*). In such experiments, subjects are typically run for short sessions. When subjects were required to read aloud for extended periods of time, however, nonfluencies produced by delayed auditory feedback (delayed "sidetone") disappeared (*2*). New speech patterns emerged, which suggested that some of the disruptions reported may be transient phenomena. For example, an initial stutterer avoided blocks or arrhythmias by slowing his rate of reading to six words per minute (*3*). The verbal response "then came John" can be represented in relation to its delayed auditory stimulus to the speaker in this way:

R: ð ɛ ɛ ɛ . . . ɛ ɛ n
S: ð ɛ ɛ . . . ɛ ɛ ɛ n
R: K e e e . . . e e ĭ m
S: K e e . . . e e e ĭ m
R: d ʒ ɑ ɑ ɑ . . . ɑ ɑ n
S: d ʒ ɑ ɑ . . . ɑ ɑ ɑ n

During normal speech, response and stimulus overlap in time. By stretching out each word, the speaker can reinstate the normal overlap, for the medial part of each word, at least. Beginnings and ends of words still display the asynchrony produced by delayed feedback. By increasing the proportion of medial to bounding units, the speaker increases the similarity between normal and delayed feedback. Others solved the problem of delayed feedback without slowing down. Some lowered their voices; others "spat out" the words or read without normal inflection. These results can also be interpreted as ways of restoring "normal" conditions. Verbal behavior produces stimuli other than those carried by air. These may be bone-conducted stimuli, or laryngeal, labial, and other proprioceptive stimuli from the vocal apparatus, and these may not be altered by the delayed sidetone. By lowering his voice, the speaker may increase the relative importance of the normal feedback. In contrast to prolongation, however, the reinstatement is of nonauditory stimulus control. Again, the absence of normal inflections in some subjects may mean that, stated intuitively, the speaker may not be listening to himself. This possibility has been studied in the following way.

Normally fluent college students read continuously from a novel for 90 minutes each day for several weeks. Each subject spoke into a microphone and heard himself through matched Telephonic TDH-39 earphones. An Ampex 601 delivered normal sidetone, at an intensity level judged sufficient to overcome bone conduction for each subject. An Echo-Vox Senior was matched in volume, and provided for adjustable delay. Every tenth word read was recorded by a monitor and transmitted to cumulative recorders and digital counters. When reading rate was stable, varying periods of delayed and normal sidetone were introduced and maintained until the reading rate recovered. Then, for periods of 10 minutes, started and terminated by auditory signals, the subjects were instructed to read as rapidly as possible and either (i) not to listen or (ii) to listen to their reading.

Figure 1 shows words read per minute during such consecutive periods by two subjects, listening or not listening, as instructed, and with sidetone normal or delayed (*4*). The reading rate tends to be low for "delay-listening" conditions and higher for the other three conditions: "delay-nonlistening," "normal sidetone-listening," and "normal-nonlistening." For subject B, day 1, the first range was 163 to 196 words per minute; the second was 217 to 261 words per minute. On day 2, the ranges were 185 to 194, and 231 to 256. Subject G showed ranges of 206 to 209, and 214 to 232. On 2 days, the highest rates were under *delay* conditions (period 6 for subject B on day 1, and period 4 for subject G).

These data support the assumptions that verbal behavior is under control of stimuli produced by preceding responses, and that one method of maintaining the behavior under new conditions is to reinstate some fraction of earlier conditions (*5*), including tem-

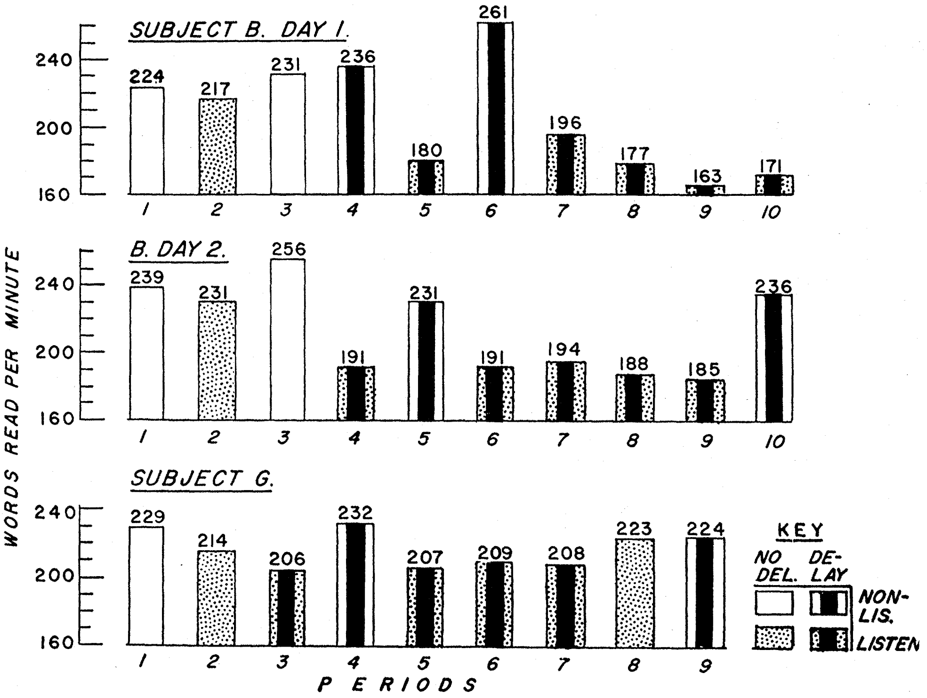

Fig. 1. Reading rate as a function of normal and delayed sidetone, when subject is under instructions to listen and not to listen.