SIMPLE TRANSDUCERS TO DETECT OR RECORD OPERANT AMPLITUDE[1]

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Part of the emphasis on rate as a behavioral measure may stem from its ease of recording. A microswitch suffices to tally the traffic. On the other hand, if one is interested in response amplitude beyond the bare stipulation that the response be big enough to close the switch, one finds the devices that have been used thus far in its investigation either single-valued, like the microswitch itself, or else expensively elaborate.

Skinner's ballistic pendulum (Skinner, 1938) had an excursion which was a function of the force of the lever press. An adjustable electrical contact closed when the pendulum made the minimum required excursion. Information obtained on response amplitudes was thus no more extensive than could be had from a microswitch with adjustable stiffness.

Notterman's apparatus (Notterman, 1959) measures force, duration, and time integral of force, and, in addition, delivers reinforcements automatically on the basis of preselected contingencies. All this is achieved by electronic manipulation of minute signals generated by strain gauges on the lever. The engineering sophistication entailed, as well as the cost of the equipment (which includes an analog computer), makes it safe to say that Notterman's achievement will not soon be duplicated in many other laboratories.

Meantime, we wish to report a new-type pressure transducer which may lead to a simple and inexpensive solution of the problem of amplitude measurement for operants. Exploratory work in our laboratory indicates it is potentially applicable with advantage in perhaps all experimental situations that involve measurement of the force with which an operant is emitted. Optimum arrangements for mounting and actuating it will no doubt be attained most quickly through the collective inventiveness of a number of interested investigators. To that end, we shall present here what information we have on its technical characteristics and describe our prototype devices for putting it to work in the psychological laboratory.

The principle involved is that when rare earths are processed with zirconium tetrachloride, resins are produced which undergo a large change in electrical resistance upon physical compression. These resins are now on the market in fluid form as "pressure-sensitive paints" or as plastic wafers already sealed into miniature metal casings and known as "pressure cells."

A variety of pressure-sensitive paints are available in 1-ounce bottles (1960 price: $30 per ounce). Sensitivity varies according to type from a resistance change of 100 ohms per pound of force to 100K ohms per ounce of force, and pressure ranges vary according to type from 0–1 pound to 0–20 pounds.

The paint is applied as a thin spot on a conductive surface, such as smooth metal, and dried overnight. Pressure may then be applied by a conductive spot to the top of the paint. This third layer we shall call the "contactor." Electrical leads attach to top and bottom layers. Current flow depends on the squeezing of the middle layer, the pressure-sensitive spot of paint. It is claimed that hundreds of such transducers can be made from a single ounce of paint.

The force applied may be read from an ohmeter by suitable calibration of its scale, or, after insertion of a battery into the circuit, on a 0–1 recording milliameter. Without amplification the output is sufficient to operate relays, recorders, scopes, and tube circuits, or even to control the speed of miniature motors. With amplification, it is claimed that force changes at the microgram level may be detected.

Resistance changes are reportedly negligible with temperature variation from −20° to 300°F, and the transducer is supposed to repeat its performance millions of times without wear. Either AC or DC may be put through it, and power limitations are set primarily by local heat-dissipation factors. Frequency response cuts off at approximately 80 cps, but processing to special order may raise it as high as 3000 cps. (Incidentally, all specifications reported here apply to low-cost stock items; some custom jobs mentioned in the manufacturer's literature have tremendously higher performance characteristics.)

Our preliminary work with pressure-sensitive paint indicates that it may be immediately put to work in applications that do not require good linearity and where unreliability up to about 10% can be tolerated. The difficulty is not with the paint itself, but rather with bringing the contactor to bear on the paint at the same place each time and at the same angle. Further "fooling around" with ways of putting the sandwich together will probably bring substantial improvement.

Our only contactors so far have been metal surfaces not bonded to the paint. An alternative might be to make the third layer of conductive paint, or conductive epoxy, and thus stabilize its interface with the pressure-sensitive paint, with pressure then to be applied by a smooth surface external to the electrical circuit. This could be a small plastic plate—a touch spot for the human finger, rat's foot, pigeon's beak or whatever.

Pressure transducers need not be round and flat. One now in use in research with monkeys is on part of the

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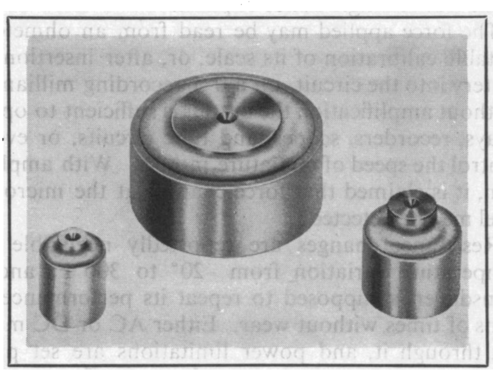
surface of a small wooden ball. The ball has been sawed through, and the paint, contactors, and a spring are between the two halves. When a monkey seizes the ball and compresses the slot, it tightens the painted surface enough to activate the relay.[2]

After finding our homemade transducers unsuitable for precision work without further development, we tried the pressure cells mentioned earlier. Our selection of samples to test was from the miniaturized version called micro-ducers. Figure 1, reproduced from a photograph in the manufacturer's literature, shows several of these. They consist of small brass shells filled with pressure-sensitive plastic and topped with a polished brass plate. The sandwich, obviously, is ready-made, and the top layer is not subject to slippage. Diameters of the cells pictured are 0.25, 0.375, and 0.75 inch. The 1960 price is $18 each.



"MICRO-DUCERS"

Fig. 1. Photograph of three pressure cells.

Micro-ducers give a highly linear change in resistance over most of their force range, and it is simple to preload them so as to restrict operation to the linear part of their curve. We have found their repeatability quite satisfactory, and the manufacturer claims that it is better than 1 ohm in 1000 ohms.

So far, work in our laboratory has been aimed at the development of a rat lever and a pigeon key, and the work has been directed along three fronts: 1) the design of the manipulandum, 2) suitable calibration and recording, and 3) the effects on experimental subjects of a rigid manipulandum.

Three pigeon-key designs have been tried, one with the pressure paint and two with the cells.[3] The first two models used a 1:1 relationship between the point

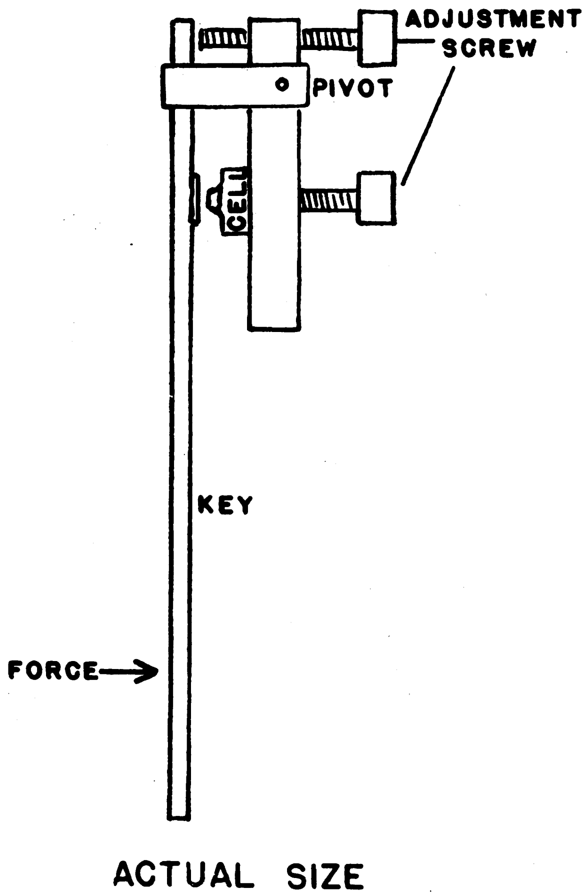


Fig. 2. A pigeon key for detecting force of peck.

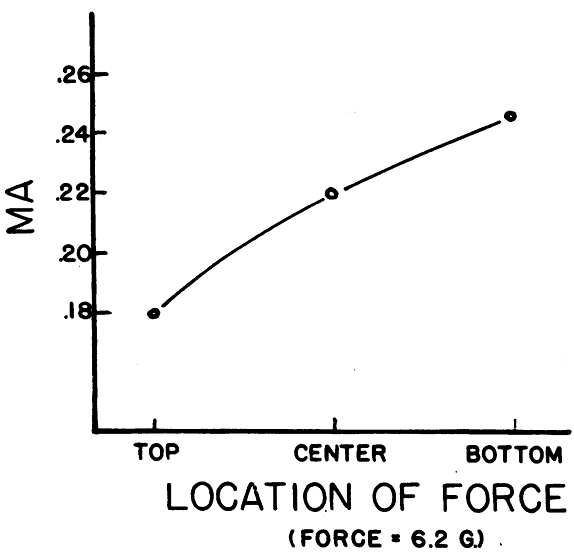


Fig. 3. Variability of pigeon key due to location of force.

[2]This application was kindly reported by Edward Taub, Jewish Chronic Disease Hospital, Brooklyn, N.Y.

[3]We express thanks to Bell Telephone Laboratories, Murray Hill, N.J., for making facilities and technical services available to us in this application.

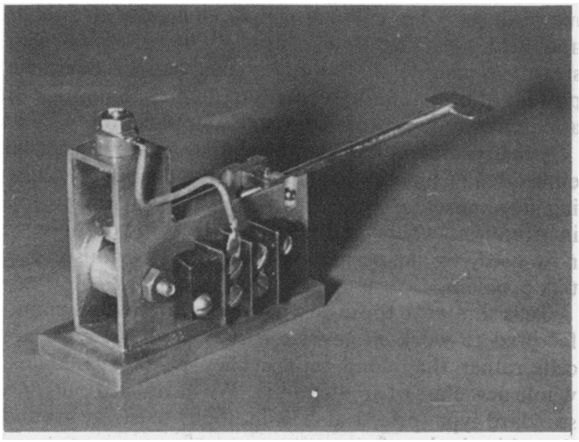


Fig. 4. Rat lever for detecting force of pressing.

of pressure and the paint or cell. Both proved to be relatively insensitive to forces of brief duration partly because of the key suspension or mounting mechanism. The third design, shown in Fig. 2, allows the force to work through a leverage. This arrangement has given more satisfactory results, but it too is limited in that the force works through a different mechanical advantage depending on whether the key is struck high or low. Variability due to this feature is shown in Fig. 3. This key is simple and can be rather precisely adjusted by means of the two set screws which vary the preloading pressure.

Figure 4 presents the lever with which we have been collecting force data from rats. Careful machining,

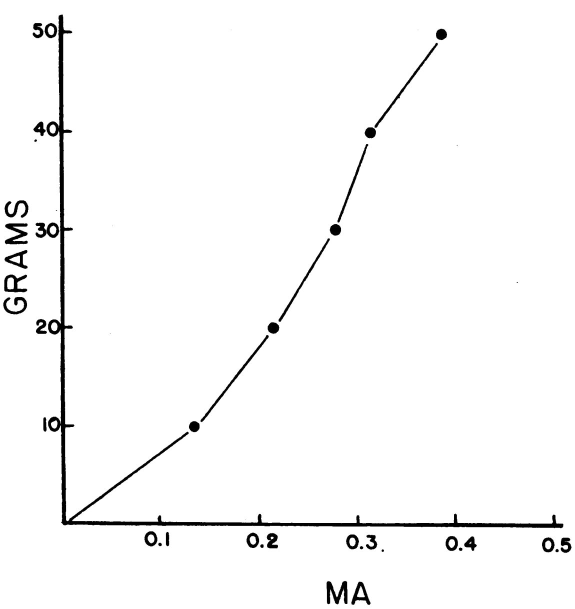


Fig. 5. Calibration curve for rat lever.

bronze bearings, and several adjusting screws make this a fairly precise unit which retains its calibration for a number of sessions. One great difficulty with a lever is that like the pigeon key, there is a difference in force depending on where the animal strikes it. We tried to minimize this error in our present bar by arranging its mounting so that once the animal was shaped up, the bar could be withdrawn until only a tiny edge protruded into the chamber. A calibration curve for this bar was obtained by dropping known weights a known distance upon the bar. This is shown in Fig. 5.

We chose to build a force manipulandum in the form of a lever only because we were slaves to tradition. Future bars, arranged singly or in multiple, might be very small treadles, buttons, loops, or almost anything the experimenter could desire.

Calibration of the milliameter used with the pigeon key was attempted, with a pendulum which struck the key with a duration assumed to resemble that of a

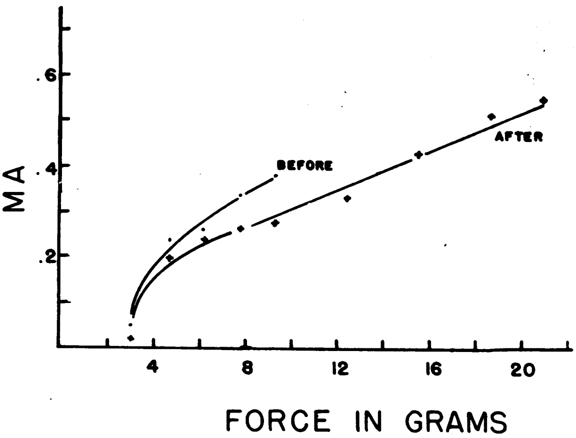


Fig. 6. Sample calibration curves for pigeon key before and after an experimental session.

pigeon's response. How warranted this assumption may be is uncertain. The technique has been to release the ball pendulum a known distance from the key, allowing it to strike the key at the bottom of the arc or rest position. Though the results have been encouraging, the method, at best, is crude. Figure 6 gives a sample calibration curve. The present key changes its characteristics slightly during a session, and so must be calibrated both before and after the session. This can be most readily corrected by providing a locking device on the set screws.

While there were no noticeable side effects of a rigid bar on the behavior of a rat, such was not the case with a pigeon. The two birds used had had brief CRF histories on conventional keys, but they transferred readily to the new situation. Figure 7 gives a sample of a bird's record, and Fig. 8 presents a distribution of forces during one session. (Figure 9 presents comparable data

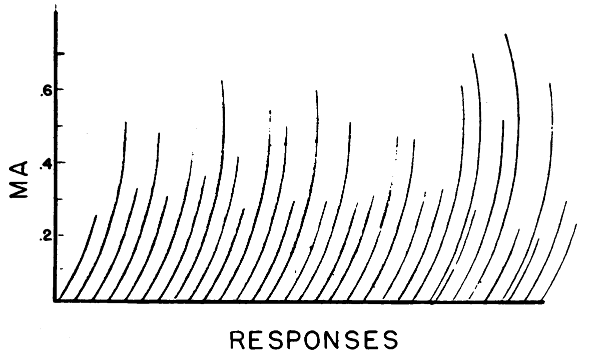


Fig. 7. Sample tracing of portion of pigeon-response record on force key.

from the rat lever.) The persistent "excess force" diminished little over the few days the birds were run, and, because of the rigidity of the key, had a rather severe effect on the beak and wattles of the bird. With fewer than 30 responses, both birds began to bleed around the beak, and eventually stopped responding. At the next session the response had to be shaped up again. Persistence of the overshoot will perhaps make prolonged running with a rigid key too damaging to be practical.

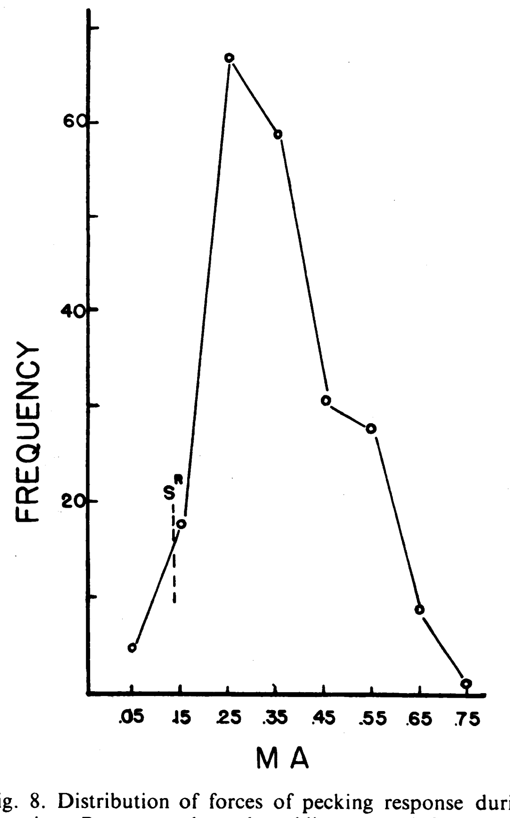


Fig. 8. Distribution of forces of pecking response during one session. Responses above dotted line were reinforced.

An effective start has been made on a heart-rate micro-ducer.[4] The cell was simply embedded in rubber and held over the "pulse artery" by a wrist-watch strap. A couple of flashlight cells supply adequate power. Pulse-amplitude measurements, though, will apparently require some degree of amplification.

A neurosurgeon has suggested that micro-ducers be embedded in functioning muscle as a means of studying intramuscular pressures.[5] Such an arrangement, in situations where multichannel electromyography is now used, would perhaps eliminate the serious cross-talk problem.

Cells similar to those described above are also manufactured to work in reverse—that is, they are strain cells rather than load cells. They make available a whole new class of applications. We have used one of a standard type (priced at $38 in 1960) to strap around the subject's chest for measurement of respiration.

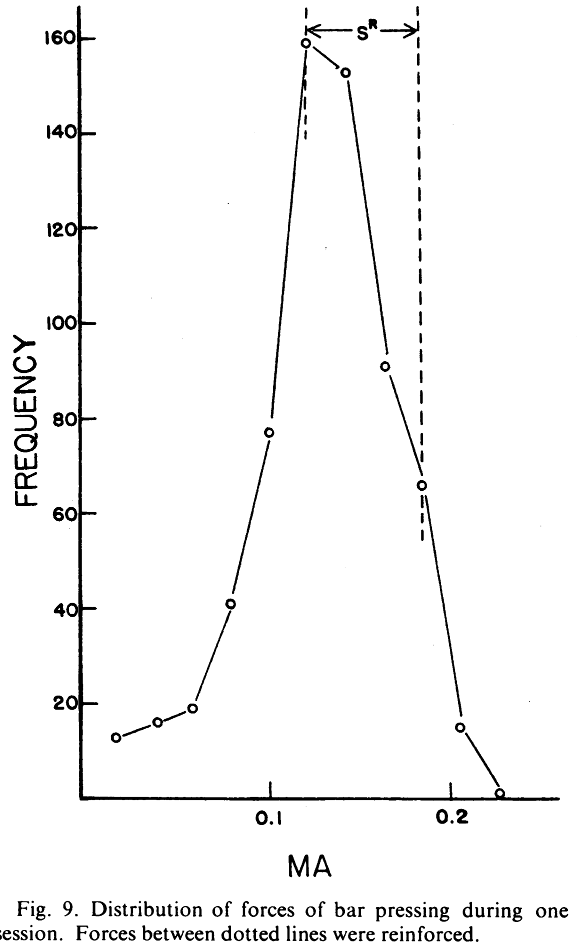


Fig. 9. Distribution of forces of bar pressing during one session. Forces between dotted lines were reinforced.

[4]This application is being developed by Richard Pescevich.

[5]This application was suggested by Dr. A. J. Berman, Jewish Chronic Disease Hospital, Brooklyn, N.Y.

As mentioned earlier, pressure transducers can be programmed for simple or elaborate control functions by conventional circuitry. Stipulated pressures can readily trigger automatic reinforcers, S^D presentations, timers, counters, and other laboratory gear. For example, we are presently counting ten different sizes of lever press by means of a battery of appropriately biased thyratrons.

Also, by operating the transducers on AC, the various advantages of magnetic tape become available, including repeated processing, change of playback speed, audio or video monitoring, and feedback to the subject.

In addition to their present or potential usefulness in perhaps all research situations where load or strain must be measured, we see this new type of pressure transducer as a means of upgrading the laboratory course work of undergraduate and graduate students. The electrical system involved is simple, inexpensive, and noise-free. Problems can be tackled which were previously out of reach because of the elaborate instrumentation they required. Where permanent recording is still too costly, surplus meters make dial reading an available technique.[6]

REFERENCES

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[6]Literature and prices on the materials described can be obtained from Clark Electronic Laboratories, Box 165, Palm Springs, Calif.