Human force differentiation: Indifference to pressure*

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A force of 150 g (1.47 N) was differentiated in two human Ss. The diameter of the circular lever surface they pressed was varied to achieve pressure differences on the responding finger. Neither the central tendency nor the variability of the performance were influenced by the variations in pressure.

Mintz & Notterman (1965) have shown systematic effects in the precision of differentiated force in human operant behavior related to the absolute level of force emission. They reported greater variability with greater force but a general decline in the relative variability over a range from 25 g (.25 N) to 200 g (1.96 N). The present study was aimed at examining the contribution of pressure sensation to force precision. The method involved requiring a constant force while the pressure at the fingertip was systematically varied.

METHOD

The Ss were one male and one female undergraduate. Both were experimentally naive; both were right-handed.

The test system included a stationery force transducer on which the Ss responded with the right index finger. The contact surfaces were the polished ends of aluminum rods. Five contact surfaces were used: 1.6, 3.2, 6.4, 12.7, and 25.4 mm in diam. A 25.4-mm-diam wooden dowel was grasped by the Ss when responding. This handgrip was positioned to provide comfortable placement of the extended index finger over the horizontal contact surface. The Ss were seated comfortably and provided with a cushion support for the right forearm.

The contact surfaces were attached to a Satham Model UC-3 force transducer and Model UL4-1 load cell. These converted the applied force to a linear voltage analog. This voltage was applied to an amplifying circuit for calibration. A threshold circuit was set for a force of 50 g (.47 N). A response began when this force was exceeded and ended when the force fell below this level. A peak detect-and-hold circuit maintained a voltage analog of the highest force achieved during the response. A Hewlett-Packard Model 561B printer recorded this peak

force after each response. Printout was resolved to whole grams. The system was capable of a maximum of 5 responses/sec, a rate far exceeding that which was produced by these Ss under these conditions.

Feedback to the Ss was in the form of a high contrast three-digit white-on-black video display. The numbers were approximately 80 mm high. The Ss' peak force in grams was flashed on the screen at the end of the response and remained there until the next response was completed. Earphones with white noise provided auditory masking during the experiment.

The Ss were seated in an isolated corner of the laboratory, approximately 1.5 m from the video monitor.

The two Ss each made a total of 250 responses in two blocks of 125 for each diameter on each of 9 test days. Successive trial blocks with any one contact surface were separated by rest periods of 5-6 min, with slightly longer rests between changes of contact surfaces.

Contact surfaces were presented in a semirandom order over the 9 days of testing.

The Ss were instructed to respond as close to 150 g as possible.

The first 25 responses of each block of 125 were omitted from data analysis.

RESULTS AND DISCUSSION

Table 1 provides the means and standard deviations of the peak force distributions over the 9 days of training. For this data, the performance on all five variations of lever diameter were combined, the statistics thus based on populations of 1,000 responses. It is clear that progressive training influences the variability of the performance. The means show no systematic change over the 9 days and are invariably close to the target value of 150 g (1.47 N). Asymptotic performance is suggested for both Ss, although S1 generated the least variable performance on Day 9.

The standard deviations on the final

days of training are consistent with results reported by Mintz & Notterman (1965), although different Ss and a different test system were involved. In that earlier study, standard deviations at a 150-g (1.47-N) target ranged from 10.4 to 15.6 g for the four Ss tested.

Table 2 shows the means and standard deviations as a function of the diameter of the contact surface. In this table, performance on the final 3 days of testing was combined, 600 observations thus contributing to each distribution. The differences among the several diameters are small, and no consistent pattern is evident. The small, but regular, increase in mean with an increase in diameter for S1 is not replicated by S2. Similarly, the differences among the standard deviations are irregular and small in size. The general effect emerging from Table 2 is that contact surface diameter does not systematically influence the performance.

Notterman & Mintz (1965) have suggested that the differentiation of response of the sort characterized by the present procedure is critically related to the Ss' discrimination of cutaneous and proprioceptive sensation generated by response emission. In the present procedure, the requirement for a constant force presumably required equivalent muscle action regardless of diameter size. In essence, diameter manipulation affected local pressure sensation, while proprioception was held constant. Assuming pressure was equally distributed over the entire contact area, pressure ranged from .296 g (.0029 N)/sq mm for the 25.4-mm diameter to 75.75 g (.743 N)/sq mm for the 1.6-mm diameter. Although equal distribution of pressure on the entire contact surface is unlikely for the largest diameter and there may have been local variation for smaller diameters, it is safe to assume a monotonic inverse relation between pressure and contact area. Whether pressure or, as Geldard (1953) suggests, force per unit linear extent is the appropriate determinant of

Table 1
Mean and Standard Deviation of Peak Force
on Successive Days of Training (Grams)

Day	S 1		S 2	
	Mean	SD	Mean	SD
1	152.0	29.6	148.5	22.6
2	154.0	15.3	148.5	16.1
3	153.8	14.0	147.4	16.1
4	152.2	13.4	150.6	16.1
5	156.1	13.6	146.9	17.2
6	155.2	14.1	148.5	15.3
7	155.6	13.7	148.9	13.8
8	154.9	12.7	149.4	13.9
9	154.0	12.3	150.4	13.8

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Table 2
Mean and Standard Deviation of Peak Force on Various Contact Surface Diameters (Grams)

		Diameter (mm)				
		1.6	3.2	6.4	12.7	25.4
S 1	Mean	153.4	154.1	154.7	155.3	156.7
	SD	13.4	13.2	12.9	12.0	12.6
S 2	Mean	150.3	149.1	148.4	149.7	150.3
	SD	13.3	12.9	14.2	14.6	14.2

pressure sensation, the present procedure clearly generated a considerable range of sensational variation in the emission of force. The invariance in the performance in the face of this variation in pressure sensation provides a dilemma.

Although the present procedure is essentially a free-operant differentiation of response, as Mintz & Notterman (1965) have noted, the procedure bears similarities to the psychophysical method of average error. The S here "matches" an implicit standard related to sensory feedback from prior responses and the digital feedback of these response magnitudes. The standard deviation then becomes an index of the difference threshold. The proportional difference in pressure sensation between, say, a 150- and 160-g (1.47- and 1.57-N) response is, of course, constant regardless of the absolute level of pressure. The invariance in performance observed across the variations in absolute pressure could reflect a manifestation of Weber's law. The Ss' resolution of forces is a constant related to constant proportional resolution of pressure. An explanation of this sort is difficult to reconcile with Mintz & Notterman's (1965) data, where variability was not a constant proportion of the absolute force or, in that case, of absolute pressure as well. Additionally, it is unlikely that a Weber's law sort of invariance would hold true over the range of pressures explored, the highest exceeding the lowest by a factor of 256.

A possible explanation may rest in the contribution of proprioceptive sensation to force emission. At the 150-g (1.47-N) level, proprioception may play a predominant role. The invariance of performance may reflect nothing more than the same muscle action in emitting 150-g responses regardless of the pressure at the fingertip. An implication of this possibility is a range of force emission where pressure variation will determine the precision of the behavior. It is likely that performance at any force level will relate to the acuity of the sensory system most differentially acute or reliable at that level. At low levels of force, for instance, pressure sensation may be

the dominant factor in performance, whereas higher force levels may

incorporate proprioceptive acuity. Future research will attempt a further analysis of pressure and proprioceptive sensation in force emission.

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The capacity of memory loci in artificial memory*

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The ancient mnemonic system of artificial memory taught a two-part process. First, a set of successive locations was committed to memory; then lists were memorized through making bizarre associations between successive list items and successive locations. This study measures the capacity of locations in artificial memory. A set of 32 English words were the list items. One, 2, 4, 8, 16, or 32 locations were used, as well as a control condition in which no mnemonic instructions were given. The results approximate a normal ogive, with the 50% point of accurate recall occurring with 8 locations, i.e., four items per location.

The ancient art of artificial memory (Yates, 1966) is relevant to modern concern with associative learning in the context of a theoretical evaluation of the concept of mental imagery (Bower, in press; Bugelski, 1970; Paivio, 1969). In this laboratory, the goal of the exploration of the artificial memory system is a search for methods to defeat the effects of neurological disorders that interfere with normal memory (Crovitz, 1970). We have found that self-produced memory maps are not a necessary part of the artificial memory process (Crovitz, 1969), nor are self-produced bizarre images (Briggs, Hawkins, & Crovitz, 1970). Thus, it is now known that inexperienced Ss can do quite well in memorizing a long list of words in a single trial using a simplified version of the artificial memory system with memory loci and bizarre mediators supplied by E.

According to Yates (1966), one problem in the use of the artificial memory system remained unsolved in historical times, and led to the greatest difficulties. It is the problem of the capacity of memory loci. While the author of *ad Herennium*, the classical source textbook of the artificial memory, wrote that the same set of locations could be used over and over again in memorizing different lists, later mnemonists went to great pains to memorize a great number of loci,

Peter of Ravenna in the 15th century writing that he memorized 100,000 locations when young, and added to them.

Using the peg-word mnemonic, Bower (in press) has shown that up to 20 words may be successfully associated to a single peg. His Ss integrated the words into a story. This was done with each peg exhausted before the next was used. Bower's method must be contrasted sharply with the artificial memory method in which successive locations are associated with successive list words, one by one. If there are n times as many list words as loci, in the artificial memory system, the set of loci would be used n times, with n runs through the set of loci and successive one-by-one associations made on each run.

The present experiment explores multiple associations to memory loci using the artificial memory system.

METHOD

The Ss were 70 Duke University undergraduates who served as part of a course requirement. At the start of their participation, they were entirely naive concerning the mnemonic system of the artificial memory. The Ss were tested individually.

A set of 32 English words was selected as the word list to be memorized in a single trial by all Ss. It was given in a constant order with a period of 10 sec between successive words, using a tape recording. The word list was: apricot, stone, doll,

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