

Phenotypic and Genetic Relations Between Initial Response to Electric Shock and Rate of Avoidance Learning in Mice

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Abstract:

The first experiment was designed to determine what proportion of the between-strain variation in rate of avoidance learning could be attributed to strain differences in sensitivity and response topography to electric shock. Measures of jumping at six shock intensities for four inbred strains were collected in a pretest of shock sensitivity. They were then used to derive a shock intensity for each strain which yielded the same amount of jumping for all strains. Avoidance training was administered to other mice of the same age and strains using the same apparatus and shock source as in the pretest. When training was given with a 180 pa shock, significant strain differences were observed in latency of the first escape and total errors to a learning criterion during both jump-out and one-way avoidance training. A large strain by training procedure interaction was found, as well. When training was administered with shock levels which yielded equal jumping in the pretest, strain differences in latency of the first escape were totally eliminated. However, the magnitude of strain differences in the rate of avoidance learning was not changed substantially. A second experiment examined two F₁ hybrid strains and a four-way cross of the inbred strains tested in the first experiment. Results indicated that initial response to shock is characterized by intermediate inheritance, while rate of avoidance learning exhibits significant dominant inheritance. Although significant genetic differences in both initial response to shock and rate of avoidance learning were detected in the present experiments, it is concluded that the former cannot account for the latter.

Article:

INTRODUCTION

Numerous experiments have provided evidence for genetic differences in avoidance learning ability in mice. Comparisons of inbred strains have been reported using shuttle (Royce and Covington, 1960; Bovet *et al.*, 1966), jump-up (Schlesinger and Wimer, 1967), and wheel-turn (Zerbolio, 1967) avoidance training procedures; all experimenters observed large strain differences. Shuttle avoidance learning has been studied with the methods of the diallel cross (Collins, 1964) and selective breeding (Bovet *et al.*, 1969) as well.

The bases for these genetic differences in avoidance learning, however, are not known. Several researchers have attempted to account for strain differences by studying other aspects of the strains which were believed to be important in the learning process.

For instance, fear or emotionality, which is implicated in avoidance learning by the two-process theory (Mowrer, 1947), has been suggested as the basis for strain differences. Studies which examined shuttle avoidance revealed similar strain differences in conflict-induced freezing (King and Mavromatis, 1956), skin resistance decrease (Carran *et al.*, 1964), and response to chlorpromazine (Fuller, 1966). Interpretation of these results is obfuscated by the lack of agreement between studies. King and Mavromatis reported that the more "emotional" strain performed shuttle avoidance more poorly, while Carran *et al.* observed precisely the opposite outcome.

Memory interpretations of avoidance learning differences have also appeared. Several studies have found one strain of mice to be superior to another at short intertrial intervals but inferior at a 24 hr interval. Bovet *et al.* (1969), using shuttle and step-through avoidance tasks, characterized the C3H/HeJ strain as one having good short-term retention, while they claimed that the strain DBA/2J possessed good long-term memory. Wimer *et al.* (1968) reported trial-spacing differences, although they found DBA/2J best with massed trials, which contradicted Bovet's results. More recent data further contraindicate the memory interpretation (Duncan *et al.*, 1971).

Other studies have suggested that strain differences may be a manifestation of differences in reaction to the training stimuli. Carran *et al.* (1964) found that strain differences in shuttle avoidance learning disappeared at high shock intensities. Similar findings were reported for passive avoidance with several intensities of aversive air blast (Carran, 1967). Even the nature of the conditioned stimulus (buzzer or light) was shown to be important (Oliverio, 1967).

From the above studies, it is clear that no single variable can account for strain differences in avoidance learning at the present time. Perhaps all the variables are important. On the other hand, none may be relevant at all, for the correlation of traits in inbred strains is not conclusive evidence of a causal relation. They may simply occur together by chance through the processes of allele fixation during inbreeding. It is important to demonstrate that the behaviors in question are correlated in cross-bred and genetically heterogeneous strains as well as across the inbred strains.

Another shortcoming in most of the above studies is that they have not gone beyond a demonstration of genotype—training condition interaction. Specifically, they generally have not measured the variable of interest, be it emotionality, memory, or sensitivity to shock, independently from the learning task itself. The experimental designs have all been inadequate to specify relatively how much of the strain differences in learning could be accounted for by some other variable; they simply tested the null hypothesis and thereby attempted to demonstrate a statistically significant relation.

The present experiments were designed to determine the extent to which genetic differences in rate of avoidance learning can be attributed to similar differences in another measure of behavior, in this case sensitivity and response topography to shock. Sensitivity to shock presumably reflects the level of motivation produced by a particular shock intensity. Since learning of a simple avoidance response is more rapid at higher shock levels within a strain (Theios *et al.*, 1966), strain differences in sensitivity to shock might result in differences in learning rate. Roberts (1967) reported strain differences in activity and skin resistance during several intensities of shock, but he did not relate them to avoidance learning. Carran *et al.* (1964) reported that three strains differed in shuttle avoidance learning only at low and intermediate shock voltages, but they presented no data demonstrating actual differences in reaction to any one level of shock.

The topography of the response to shock may also be important. Those animals whose initial response to shock is more similar to the correct avoidance response may learn faster, even though no differences in sensitivity to shock exist. Zerbolio (1967) suggested that the strains which performed best in wheel-turn avoidance training were those which jumped instead of ran during shock, but he presented no relevant data on jumping. Bolles (1970) recently discussed the importance of species-specific defense reactions in determining rates of avoidance learning, but he did not attempt to relate the notion to differences among strains within a species.

EXPERIMENT 1

In the first experiment, strain differences in responses to shocks of six different intensities were measured with an apparatus which allowed reliable recording of jumping and squealing. The same apparatus was later employed with minor modifications during avoidance training of other mice of the same age and strains. The apparatus could also be modified to allow either jumping, running, or both to function as escape and avoidance responses. Strains which reacted to shock by jumping were expected to learn to avoid faster than strains which ran when the correct escape and avoidance responses were jumping, while they were expected to be at a

disadvantage when the correct response was running. Thus the behaviors observed during the shock sensitivity pretest could be correlated with learning rates when different responses were required.

The most important aspect of the design, however, was the use of the jumping data from the pretest to derive levels of shock for each strain and sex which equated them for the amount of jumping. Half of the Ss were trained in avoidance with a single shock intensity, and half were given the intensity which equated jumping to the shock. The consequent reduction in between-strain variation in avoidance learning resulting from training with equated jumping estimated the proportion of genetic variation in avoidance learning which could actually be attributed to genetic variation in response to shock.

Method

Subjects

Forty-eight male and 48 female mice of each of the inbred strains A/J, CBA/J, C57BL/6J, and DBA/2J were obtained from the Jackson Laboratory, Bar Harbor, Maine, at 7 weeks of age. The mice were received and subsequently tested in groups of six of each sex and strain per week for 8 consecutive weeks; they were housed in groups of six mice of like sex and strain. All mice were maintained on a 12-12 light—dark cycle with free access to water and dry food.

The four strains were chosen following the collection of preliminary data on activity and squealing to shocks of several intensities by eight different inbred strains. The chosen strains covered the range from low to high activity during shock. No data were available on avoidance learning ability of these strains at the time they were selected for study.

Apparatus

Resistances of the Ss' feet were measured with a Simpson model 312 VTVM via a wound clip inserted into skin at the nape of the neck and a springloaded hemostat clasped firmly on various appendages.

All training was administered in two 6 inches square by 4 inches high black plexiglas boxes which shared a common wall with a 2 inches square sliding door in the center of the wall. The floor of one box (shock box) was a grid of $\frac{1}{16}$ inch stainless steel bars $\frac{3}{8}$ inch apart, while the other (safe box) was covered by smooth paper.

Photocells were located in each box 2 inches from the door and $\frac{1}{2}$ inch above the grid; two more photocells were located $3\frac{1}{2}$ inches above the grid in the shock box. The training apparatus was illuminated by a 25 w red light bulb located 48 inches above the shock grid; incident light intensity at the grid was 2.2 ft-c.

The shock box was modified for shock sensitivity testing by adding a 6 inches high plexiglas extension to the top of the shock box and placing an Electro-Voice 644 spot microphone about 10 inches above the grid at the opening of the 10 inches high box. The actual shock current flowing through S , indicated by the voltage drop across a 10 kohm resistor in series with S , and squealing, indicated by the filtered and integrated output of the microphone, were recorded during each shock on the two channels of a Brush Mark 220 recorder running at 25 mm/sec. The amplified output of the microphone was sent through a high-pass filter (3 db down at 1 kHz) and then was rectified and integrated to give a pen deflection of 1 cm at 95 db as measured by a General Radio type 1551-C sound level meter (B weighting scale) with its microphone at the same location as the spot microphone. The source of sound for calibration purposes was a 2.5 kHz pure tone from a Mallory model SC 628 Sonalert device supplied with 9 v d-c and located at the level of the shock grid pointing upward. This pen deflection could be produced by a high-frequency, wide-band squeak of about 78 db. Background noise at 62 db gave no pen deflection. Resistance of S was derived from a recording on the Brush 220 of voltage drop across a 10 kohm resistor in series with a 6 v battery, a 1 megohm resistor, and S .

To administer avoidance training, the plexiglas extension was replaced by a flat piece of $\frac{1}{8}$ inch masonite which extended out 7 inches from the rim of the shock box on all sides and which was enclosed by 8 inches high

aluminum walls. There was also a $1\frac{1}{2}$ inch strip of $\frac{1}{4}$ inch hardware cloth around the rim. Thus the *S* could jump or climb out of the shock box onto the platform. When a clear plexiglas top was placed over the opening and the door was opened, the *S* could leave the shock box and enter the safe box via the 2 inch doorway.

Shocks were derived from the secondary of a 400 v a-c transformer in series with the *S* and a variable, high resistance. The shock intensities were calibrated by measuring voltage drop across a 10 kohm resistor with an oscilloscope and a milliammeter. Nominal intensities through a 100 kohm "mouse" were 40, 75, 105, 180, 245, and 370 microamperes (μa) at switch settings with continuous variation possible between these settings. Shocks could be delivered either through a cable to a socket on a wound clip in the loose skin behind *S*'s neck with the all grid bars in common or through *S*'s feet via various grid bars when a diode bridge shock scrambler was used. In the prior instance, the only possible way to escape the shock was to jump off the grid; in the latter case, shock could be terminated by standing on a single bar or by spanning every fourth bar, but no cable or wound clip was necessary.

The timing and order of events were programmed with a solid-state system built from Digital K-series modules. Response times and photocell counts were also obtained with the Digital system.

Procedure

Ss were tested after spending 1 week in the laboratory. The mean age at testing was 55 days, with a standard deviation of 2 days. The order of testing *Ss* was balanced across strain, sex, and training condition within replications; *Ss* were randomly assigned to training conditions and testing order. The shock grid and all walls were carefully cleaned with ethanol between each *S*. All testing was accomplished during the dark phase of the light—dark cycle.

Sensitivity Testing. The *Ss*' skin resistances and reactions to six intensities of shock were measured with two different procedures in phases 1 and 2. The first allowed reliable observation of jumping to shock, while the second involved shock similar to the type of shock employed later in avoidance training.

In phase 1, each *S* was anesthetized with sodium methohexital (dose range from 65 to 80 mg/kg for various sexes and strains), a wound clip was inserted into the loose skin at the nape of the neck, and resistance readings were taken with the VTVM of the feet and tail, first when dry and then when wet with saline. After a 24 hr recovery from this brief anesthesia, sensitivity to shock was tested. A fine wire was attached to the wound clip, and a 1 min recording was made of the resistance of the free-moving *S*. Then a series of 12 shocks of 2 sec duration each and separated by about 10 sec was presented; the nominal intensities of the shocks were 40, 75, 105, 180, 245, 370, 370, 245, 180, 105, 75, and 40 μa in that order. Actual shock current and squealing were recorded during each shock. In addition, counts were obtained of the number of crossings of the upper and lower photocells during each shock.

After six *Ss* of each sex and strain were tested under phase 1, another set of 48 mice was tested in phase 2. They received neither anesthesia nor wound clips. Free-moving resistance testing and the 12 shocks were administered as in phase 1, except that current was applied through the grid bars using a diode bridge shock scrambler.

Avoidance Training. Following the completion of phase 2, avoidance training commenced with the next shipment of mice. Each weekly shipment of mice constituted one replication of a 48-cell design, which was a factorial combination of strain (A, CBA, C57, DBA), sex (male, female), training (jump-out, one-way, optional), and shock type (equal shock, equal jump). Each *S* was trained under the appropriate conditions until a criterion of five consecutive avoidances was achieved or until 50 trials were completed. Each trial began when *S* crossed the upper photocell beam while being placed into the shock box. The shock came on 5 sec later, unless the appropriate avoidance response occurred first, and stayed on for 30 sec or until the appropriate escape response occurred. The next trial began 1 min after the start of the previous trial regardless of *S*'s response

latency. *S* spent the time between trials in a holding cage. Data collected on each trial were response latency and various notes concerning *S*'s behavior.

Jump-out training was given with the center door closed and a top over the safe box. *S* was required to jump onto the masonite platform to escape and avoid. Successful jumping-out was observed by *E*, who in turn pushed a button to terminate the trial.

One-way training was conducted with the center door open and a top over the shock box. *S* was required to run through the doorway into the safe box to escape and avoid. Running-through was indicated by *S* crossing the photocell beam in the safe box, although *E* could employ the pushbutton whenever *S* missed the photocell.

In optional training, the door was open and the top was off both boxes. *S* could jump out or run across to escape and avoid. The appropriate responses were detected as described above.

All *Ss* trained under the equal shock condition received a shock of 180 μ a during avoidance training. In the equal jump condition, each strain and sex was trained with a level of shock which equated all groups for the amount of jumping observed in the sensitivity test. The average number of jumps at 180 μ a was determined across all strains. Then the shock current which gave that amount of jumping was found for each genotype using linear interpolation, as described below in the sensitivity results section.

Results and Discussion

Sensitivity Testing

Several measures of skin resistance for the four strains are shown in Table I. Resistances of dry and wet feet were measured with the Simpson meter during anesthesia; resistance while *S* was freely moving on the grid was derived from the mean of current measures taken every 5 sec during the 1 min pretest; actual resistance during shock was calculated from the actual current through *S* at the 180 μ a shock intensity. Statistical evaluations of resistances during the grid pretest and shock were actually based upon the raw data, pen deflection in millimeters, and not derived resistance.

Analysis of variance of the resistance of dry and wet feet revealed no significant differences among strains and sexes in either case ($p > 0.05$), although trends were clear. Whereas the CBA mice had significantly lower resistance than the other three strains during the phase 1 grid pretest ($F = 8.9$, $df = 1/73$, $p < 0.01$), no strain differences were apparent during shock ($F < 1.0$). In phase 2, the difference between CBA and the other three strains was significant during both the grid pretest ($F = 22.2$, $df = 1/73$, $p < 0.01$) and shock ($F = 25.1$, $df = 1/73$, $p < 0.01$). Sex differences were not significant in phase 1, but in phase 2 females had higher resistance than males during the grid pretest ($F = 18.2$, $df = 1/73$, $p < 0.01$) and shock ($F = 8.4$, $df = 1/73$, $p < 0.01$). In general, differences among genotypes were much greater when current was administered entirely through the grid bars in phase 2 than when it was given via a wound clip in the skin in phase 1.

Table I. Several Resistance Measures (Ohms 10^6)

Strain	<i>N</i>	Dry feet	Wet feet	Grid pretest	Actual during shock
Phase 1					
A	11	9.74	0.14	0.42	0.12
CBA	9	6.55	0.11	0.29	0.12
C57	12	8.25	0.12	0.46	0.13
DBA	11	6.14	0.11	0.48	0.11
Phase 2					
A	11	—	—	2.03	0.32
CBA	11	—	—	1.25	0.12
C57	12	—	—	2.45	0.21
DBA	12	—	—	2.08	0.22

Even though Ss with higher resistances draw less current during shock, these differences can be minimized with a properly designed "constant-current" shock source. The effectiveness of the present shock method was evaluated from the actual shock currents through Ss at different intensities, as shown in Table II. No differences in actual shock current among genotypes were significant in phase 1, but higher currents were drawn by CBA mice and males in general in phase 2 (both $p < 0.01$). Between-strain variability was greater at higher intensities, as predicted by Ohm's law. Variability was also greater in phase 2, while mean currents were lower than in phase 1. Nevertheless, no groups deviated more than 10% from the mean value, and there was no overlap in actual current for different nominal intensities. The genuine meaning of the variation in shock current, however, could be judged only from measurement of Ss' behavior.

Table II. Actual Shock Current at Six Nominal Shock Intensities (μa)

Strain	40	75	105	180	245	370
Phase 1						
A	38.9	69.3	99.4	174.9	243.2	378.8
CBA	38.6	69.7	101.5	175.2	246.2	379.3
C57	38.5	68.9	99.7	173.7	242.7	378.5
DBA	39.4	70.1	101.5	175.7	244.0	375.7
Phase 2						
A	35.2	67.8	95.3	160.9	222.9	347.1
CBA	37.7	70.1	101.0	174.9	243.0	372.7
C57	35.5	68.8	97.4	168.2	230.9	361.7
DBA	35.9	67.3	96.4	167.7	226.7	348.1

Behaviors measured during sensitivity training included jumping, squealing, and crossing of the upper and lower photocell beams. Since each shock intensity was given twice to each S, once in an ascending and once in a descending series, measures of each behavior were simply summed for the two shocks and treated as scores for a single 4 sec shock. Although reactions to a given intensity were sometimes different on the first and second presentations, such order effects were not of particular interest and were not analyzed. Measures of all behaviors were taken from the analog records of squealing and actual shock current, an example of which is shown in Fig. 1.

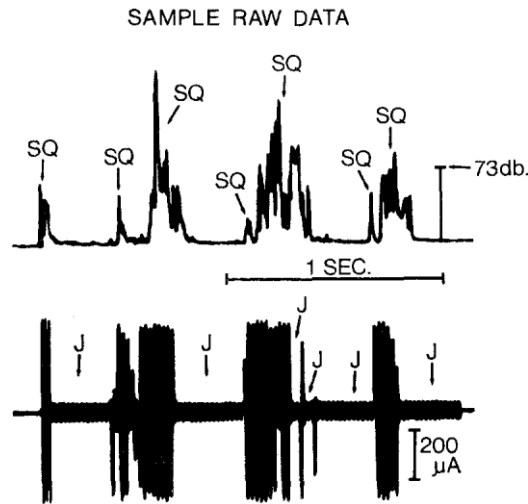


Fig. 1. Actual records of squealing and shock current from a mouse shocked at 370 μa with the procedure employed in phase 1. Presence of a squeal is indicated by SQ, while the location of each jump of 2.5 cycles duration or more is indicated by J. Calibration scale for shock current gives the RMS current (200 μa). The small current present when the mouse is off the grid results from capacitance between bars and wires. Calibration of the audio scale was derived with a General Radio 1551-C sound-level meter (B scale) with microphone at the same position as the spot microphone. The CAL mark represents a squeak of about 73 db; the scale is not linear.

Jumping was detected in phase 1 whenever the actual current dropped to a zero level, since the only way to terminate shock was to remove all four feet and the tail from all grid bars. Duration of each jump was obtained

from the number of cycles (at 60 Hz) for which current remained at the zero level, and height of any jump was derived from the relation between time of flight and maximum altitude for a projectile in motion. Since current was sometimes reduced briefly in the course of rapid running across the grid, only departures of at least 2.5 cycles (2 mm altitude) were regarded as jumps. Jumping in phase 2 could not be obtained from the shock current record, since shock could be terminated by spanning every fourth grid bar or by standing on only one grid bar. Therefore, jumping was detected by crossings of the two photocell beams $3\frac{1}{2}$ inches above the grid. This measure was not particularly accurate, since *S* could jump without breaking either beam, but it gave at least a rough estimate of relative jumping for the various genotypes.

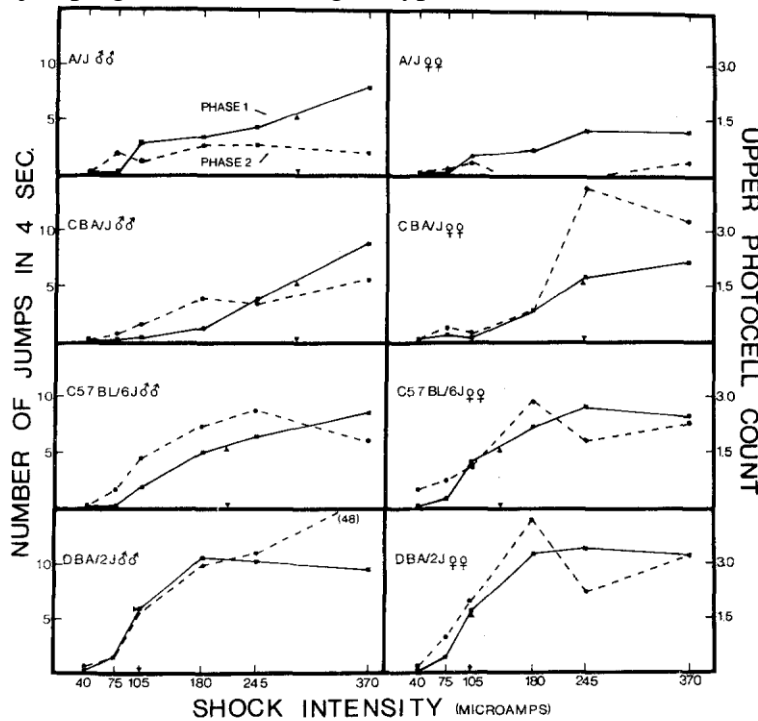


Fig. 2. Number of jumps (solid line) in 4 sec of shock at each of six different shock intensities in phase 1 and upper photocell count (dashed line) for each shock intensity in phase 2 for males and females of four strains. Small triangles touching solid line and abscissa show shock level that gives 5.63 jumps by linear interpolation.

The number of jumps at each shock intensity for the several strains and sexes in phase 1 is shown in Fig. 2, along with the analogous upper photocell count from phase 2. Strain differences in jumping were highly significant in both phase 1 ($F = 10.3$, $df = 3/35$, $p < 0.0001$) and phase 2 ($F = 18.0$, $df = 3/38$, $p < 0.0001$), while neither the sex effect nor the sex by strain interaction approached significance in either phase. A Newman-Keuls test on ordered means in phase 1 revealed that the DBA strain jumped more than the others ($p < 0.05$) but that A, CBA, and C57 did not differ significantly from one another. A similar test for phase 2 results showed that CBA and C57 did not differ significantly, but they jumped more than A and less than DBA. Thus, although the results for phases 1 and 2 were not directly comparable, they did exhibit similar strain rank-orderings. As in the case of resistance measures, strain differences in jumping appeared to be greater in phase 2. It is of interest to note that, whereas the strains CBA, C57, and DBA jumped vigorously at higher shock intensities and therefore differed only at intermediate intensities, the A strain jumped very little at any level of shock.

The jumping data were used to derive shock intensities which equated the various strains and sexes for amount used jumping. The mean number of jumps across all *Ss* at $180 \mu a$, the shock used for avoidance training in the equal shock condition, was 5.63 jumps in 4 sec. For each strain—sex group, the shock current was found which gave 5.63 jumps for that group, using linear interpolation as depicted in Fig. 2. Since the A females never jumped more than 5.63 times at any shock, the appropriate current was derived from the linear regression equation fitted to the data, $Y = 0.0119X + 0.04$, where X is in microamperes and Y is number of jumps. The equal jumping shock currents are given in Table III together with the numbers of jumps at a current of $180 \mu a$. It should be noted that shock intensities were derived for each strain—sex group, even though the results revealed

no sex difference and no significant difference among certain strains. These procedures were part of the total experimental design and therefore were carried out prior to statistical analysis of the results.

Table III. Shock Current (μa) and Number of Jumps in Phase 1 Used to Plan Shock Levels for Avoidance Training

	Genotype							
	A		CBA		C57		DBA	
	♂♂	♀♀	♂♂	♀♀	♂♂	♀♀	♂♂	♀♀
Equal shock								
Shock	180.	180.	180.	180.	180.	180.	180.	180.
Jumps	3.33	2.20	1.25	2.28	5.00	7.33	10.60	10.83
Equal jump								
Shock	295.	470.	295.	240.	210.	140.	105.	105.
Jumps	5.63	5.63	5.63	5.63	5.63	5.63	5.63	5.63

Because strain differences in jumping could have resulted from differences either in level of pain or in response topography, the squealing data were of considerable importance. They also permitted direct comparisons between phases 1 and 2, unlike the jumping data. The number of detectable squeals at each shock intensity for each *S* was divided by the proportion of time during each 4 sec of shock in which *S* actually received shock in order to reduce the bias toward lower squealing scores for *Ss* which jumped frequently. The mean adjusted number of squeals in each 4 sec of actual shock are shown in Fig. 3.

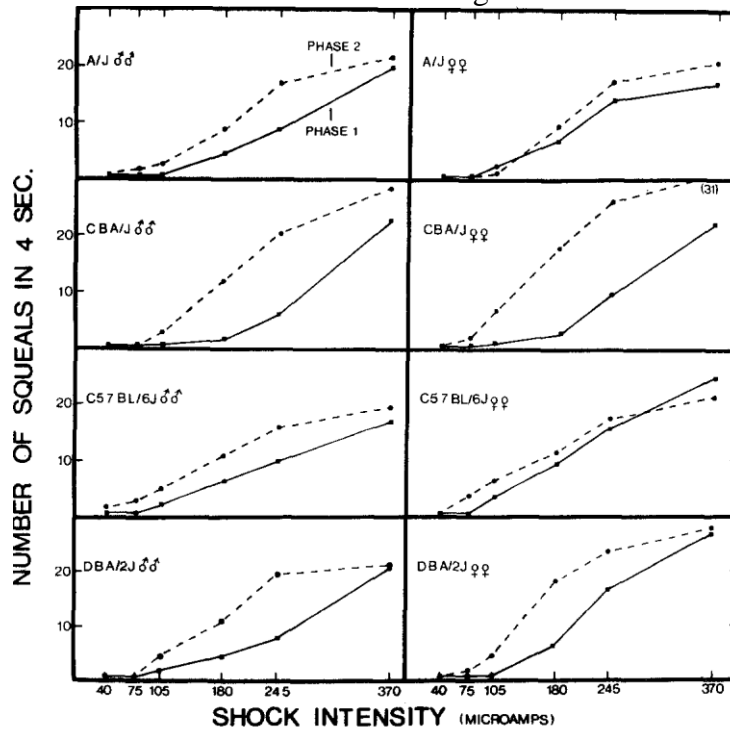


Fig. 3. Number of squeals in 4 sec of shock at each of six intensities for males and females of four strains during phase 1 (solid line) and phase 2 (dashed line).

There was significantly more squealing in phase 2 than phase 1 ($F 29.7$, $df = 1/73$, $p < 0.001$), and females squealed more than males ($F = 7.4$, $df = 1/73$, $p < 0.01$). Strain differences were not significant ($p > 0.25$), but a small strain by phase interaction was present ($F = 2.7$, $df = 3/73$, $p < 0.05$). Although each strain squealed more in phase 2 than phase 1, the difference was significant only for CBA ($p < 0.0001$) and DBA ($p < 0.01$). In fact, the CBA mice squealed the least among the four strains in phase 1 but were most vociferous in phase 2. The reason for this large difference is not known.

Thus the pattern of results for squealing was not at all similar to that for jumping, which implies that differences in jumping involved more than simply unequal levels of pain. Examination of individual protocols for 180 μa in phase 2 revealed that only one mouse, an A, failed to squeal at least once, while eight of 11 A mice and two of

11 CBA mice never exhibited jumping at that intensity. In these instances, Ss were generally observed to run in circles, although no objective measure of running was available. The independence of jumping and squealing was further evidenced by nonsignificant ($p > 0.05$) Pearson correlations between jumping and squealing scores of the eight strain—sex groups at 180 μ a in both phases 1 and 2. These findings suggest that the jumping scores reflected a genuine strain difference in response topography.

Neither jumping nor squealing was significantly correlated with actual shock current at 180 μ a in either phase, which implies that the relatively small strain differences in actual shock current were of little consequence for behavior.

Avoidance Training

The 48 treatments of the avoidance testing constituted a factorial combination of four strains, two sexes, three training procedures (jump-out, one-way, optional), and two shock conditions (equal shock, equal jump) with four Ss in each cell. The shock intensities under the equal shock and equal jump conditions are shown in Table III. Since no sex difference or interaction with sex was detected for any variable, the results are presented only for strain, training, and shock condition with eight Ss per cell.

The latencies to escape shock on the first trial, shown in Fig. 4, were in very close agreement with the strain differences in jumping observed during the pretest. The perfect negative correlation between strain rank-orders for the jump-out and one-way tasks was reflected in a significant strain by training interaction ($F = 4.4$, $df = 6/144$, $P < 0.001$). Strain differences were highly significant for jump-out training only with equal shock ($F = 8.4$, $df = 3/144$, $p < 0.0001$); no differences were evident for jump-out in the equal jump condition ($F < 1.0$). No significant strain differences occurred under either shock condition for one-way or optional training (all $p > 0.10$). Within the jump-out, equal shock condition, strains CBA and C57 did not differ ($F < 1.0$), but they escaped faster than strain A ($F = 16.1$, $df = 1/144$, $p < 0.0001$); they were not significantly slower than DBA ($p > 0.10$). The strain differences were attributable, at least in part, to differences in response topography because under the equal shock condition, strain A escaped faster during one-way than jump-out training ($p < 0.0001$), while strain DBA was faster during jump-out than one-way training ($p < 0.05$).

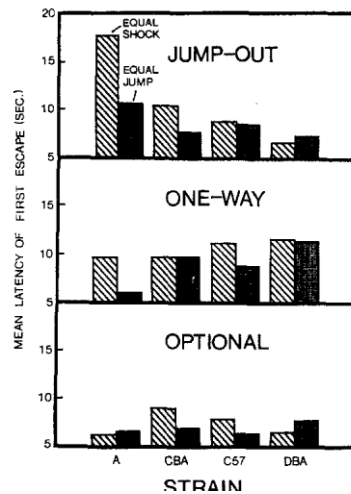


Fig. 4. Mean latency of the first escape for four strains and three training procedures under equal shock (diagonal stripes) and equal jumps (cross-hatching) shock conditions. The minimum latency is 5 sec because the shock commences 5 sec after the initiation of the trial.

Optional training yielded generally shorter escape latencies than the other two procedures ($F = 12.0$, $df = 1/144$, $p < 0.001$), which was expected, since Ss could escape with either a jumping or running response. The actual response mode on the first trial was consistent with the relative latencies when either jumping or running was the sole escape route, as presented above. The numbers of Ss out of eight which jumped out of the box on the first trial, as opposed to running through the door, in the equal shock condition were 0, 5, 5, and 6 for strains A, CBA, C57 and DBA, respectively. Corresponding numbers of jumps for the equal jump condition were 2, 7, 5, and 5.

In contrast to the first escape, the last escape prior to attaining criterion or completing 50 trials occurred quite rapidly for almost all conditions. The only exceptions were strains A and CBA under one-way training; their final escape latencies (9.2 and 11.7 sec, respectively) were considerably longer than any other condition (overall mean of 6.0 sec). This one comparison was highly significant ($p < 0.0001$) and accounted for 86% of the total between-groups variance. The remaining differences among the various other training and strain conditions were not significant ($F < 1.0$). Thus, under jump-out and optional training, all strains eventually escaped equally quickly in spite of large differences in initial escape behavior. The reasons for the relatively poor escape performance by strains A and CBA under one-way training appeared to be complex and are therefore in need of further study.

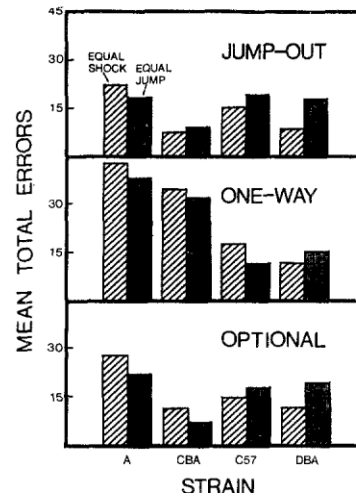


Fig. 5. Mean total errors to achieve a learning criterion or complete 50 trials for four strains and three training procedures under equal shock (diagonal stripes) and equal jump (cross-hatching) shock conditions.

Avoidance learning was expressed in total errors rather than trials to criterion because 28 of 192 Ss failed to reach criterion within 50 trials; 18 of these Ss were from strains A or CBA under one-way training. Only six Ss failed to avoid at least once. The mean total errors for the various groups are shown in Fig. 5.

Table IV. Results of Newman-Keuls Test^a of Strain Differences in Total Errors for Various Training Conditions

Training condition	Strain			
	Most errors		Fewest errors	
Jump-out, equal shock	A	C57	DBA	CBA
One-way, equal shock	A	CBA	C57	DBA
Optional, equal shock	A	C57	CBA	DBA
One-way, equal jump	A	CBA	DBA	C57
Optional, equal jump	A	DBA	C57	CBA

^a Strains connected by an unbroken line are not significantly different with $\alpha = 0.05$.

The overall analysis of variance revealed highly significant effects of strain ($F = 20.0$, $df = 3/144$, $p < 0.0001$) and training procedure ($F = 21.0$, $df = 2/144$, $p < 0.0001$). Strain interacted with shock condition ($F = 2.7$, $df = 3/144$, $p < 0.05$) and training procedure ($F = 9.6$, $df = 6/144$, $p < 0.0001$).

Strain effects were statistically significant ($p < 0.05$) for all training and shock conditions except jump-out with equated jumping, where only a small difference was evident ($F = 1.7$, $df = 3/144$, $p < 0.25$). Differences among strains within particular training conditions were evaluated with the Newman-Keuls test, the results of which are given in Table IV. The strains C57 and DBA did not differ in any condition, while the A strain exhibited the poorest performance in every condition. The CBA strain, however, performed very well under both jump-out and optional training but quite poorly under one-way training.

Within the equal shock condition, the total errors under jump-out and one-way training were not different for either C57 or DBA (both $p > 0.10$). There were significantly more errors under one-way than jump-out training for strains A ($F = 16.5$, $df = 1/144$, $p < 0.0001$) and CBA ($p < 0.0001$).

Optional training led to total error scores which were equivalent to those for jump-out ($F = 1.0$). The preferred avoidance response modes for the four strains were consistent with this outcome. Although some Ss, particularly in strain A, ran instead of jumped on the first escape trial, most Ss eventually avoided by jumping out of the box. The mean numbers of jump-out responses on the five trials of the criterion run for strains A, CBA, C57, and DBA, respectively, were 4.8, 5.0, 4.4, and 3.4 with equal shock and 5.0, 5.0, 4.8, and 4.0 with equal jumping; the data represented only those Ss which achieved criterion.

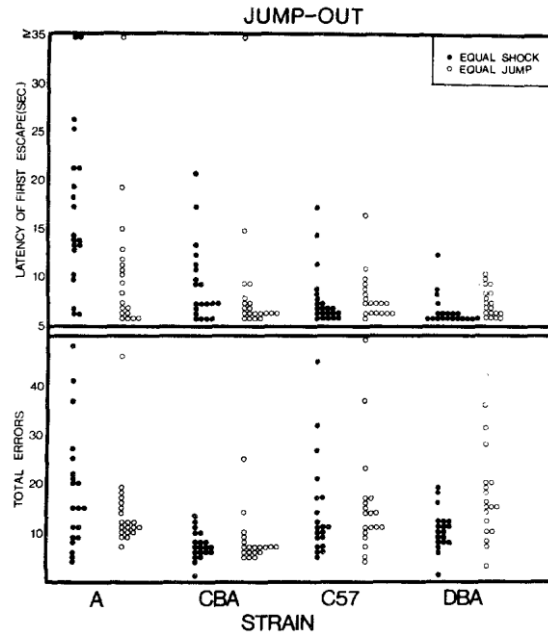


Fig. 6. Distributions of latency of the first escape and total errors for four strains under equal shock (black dots) and equal jump (open circles) shock conditions during jump-out training. Each point represents one mouse.

Relations Among Pretest, Escape, and Avoidance Learning Results

The amount of jumping for the four strains observed in the pretest was a very good predictor of latency of the first escape in jump-out training as well as response mode in optional training. The Ss in strain A, which exhibited little jumping in the pretest, were relatively slow to escape shock on the first trial of jump-out training and generally chose to run instead of jump on the first trial when given a choice in optional training.

Furthermore, jumping in the pretest was related to the first escape latency only for jump-out training; no strain differences in first escape latency were apparent in one-way training. However, the effects of initial response topography to shock were transitory. All Ss of all strains eventually escaped shock with equal celerity under jump-out training.

The rate of jump-out avoidance learning was not predictable from the strain differences in either jumping or squealing in the pretest. The CBA strain exhibited little jumping in the pretest, escaped the shock in jump-out training with only moderate speed, but learned quite rapidly to avoid by jumping; learning during one-way training, which the pretest data and latency of the first escape suggested should be as rapid for CBA as any other strain, was in fact very slow.

Thus large strain differences in avoidance learning cannot be attributed entirely to similar differences in response topography or sensitivity to shock. The question still remains, however, as to whether a significant but less than perfect relationship between jumping to shock and rate of avoidance learning exists. This is why the equal jump condition is interesting.

Effects of Equating for Jumping

The techniques employed to determine levels of shock for each strain which gave approximately equal jumping in the pretest (mean of 5.63 jumps in 4 sec of shock) and the shock intensities used for the equal shock and equal jump conditions were described above (Table III). Since the effects upon jump-out avoidance of equating jumping were of central interest in this experiment, additional Ss were trained following completion of the larger 48-cell design to obtain nine or ten Ss in each strain—sex—shock combination under jump-out training. No sex differences or interactions with sex were significant for any variable of interest; as a result, the data presented below represent 18-20 Ss per strain—shock combination. The only difference from the above results in the outcome after testing more Ss was that the small strain difference under the equal jump condition was replaced by a significant strain difference ($F = 4.4$, $df = 3/73$, $p < 0.01$).

Table V. Between-Strain Variation in Latency of First Escape (LFE) and Total Errors (TE) in Jump-Out Training with Equal Shock (ES) and Equal Jumping (EJ)

Measure	Shock type	MS _{between}	MS _{within}	df _{within}	ω^2	Change (%)
LFE	ES	446.5	25.4	76	0.383	
LFE	EJ	37.4	26.1	73	0.017	-95.7
Log (LFE)	ES	0.536	0.026	76	0.428	
Log (LFE)	EJ	0.045	0.025	73	0.030	-92.9
TE	ES	461.6	69.1	76	0.176	
TE	EJ	341.1	77.5	73	0.117	-33.4
Log (TE+1)	ES	0.368	0.052	76	0.184	
Log (TE+1)	EJ	0.308	0.042	73	0.199	+7.8

The measures of greatest interest were latency to escape the first shock and total errors in avoidance training. Distributions of these scores are presented in Fig. 6 for the four strains under the equal shock and equal jump conditions.

The question to be answered is this: To what extent is the between-strain variation reduced when Ss are trained with shock intensities that insure equal jumping as compared to training with nominally equal shock intensities? The extent of this reduction in variation is proposed to indicate the proportion of between-strain variation in escape latency or avoidance learning attributable to strain differences in initial response to shock. Since inbred strains certainly do not represent a random sample from the population of all possible mouse genotypes (McClearn, 1967), the strain variable in this experiment must be regarded as a fixed rather than random factor. Hence the appropriate measure of the proportion of total variance attributable to strain differences is given not by the intraclass correlation but by the relation

$$\text{Est. } \omega^2 = (SS_{\text{between}} - (J - 1) MS_{\text{within}}) / SS_{\text{total}} + MS_{\text{within}}$$

where J represents the number of strains (Hays, 1963, p. 382). The estimated ω^2 can range from less than 0 to +1.0; a value of 0.5 signifies that 50% of the total variance in the experiment can be attributed to strain differences. This value is sometimes known as the "strength of effect."

The variance components and derived ω^2 values are given in Table V for total errors and latency of the first escape under the equal shock and equal jump conditions for jump-out training. A logarithmic transformation of both variables was included because a mean—variance correlation was evident in the raw data. The results clearly demonstrated that equating the strains for jumping to shock reduced the between-strain variation by more than 90% for latency of first escape. However, total errors showed no such dramatic decrease in variance when jumping was equated. The equal jump condition yielded either more or less strain variation than the equal shock condition, when either transformed or raw data were employed, respectively. In both instances, the change in ω^2 was very small compared to the change for latency of the first escape. Since equating jumping was highly successful in eliminating genetic variance in latency of the first escape, it cannot be argued that the small change in ω^2 for total errors was attributable to a failure to equate properly for jumping. Given that the interpretation depends upon the scale of measurement, it may never be possible to determine precisely what

proportion of strain variation in learning can be attributable to strain differences in response to shock. The present findings suggest that this proportion is quite small and may not differ significantly from zero.

These results do not mean that equating for jumping had no effect upon avoidance learning. In fact, a new rank-ordering of strains emerged in the equal jump condition; the DBA strain had the most errors (17.6), while the A strain (14.3) was superior to C57 (15.4) but inferior to CBA (8.1). Evidently, a shock of sufficient magnitude to elicit jumping in A mice provided great motivation to avoid, once the escape response had been acquired, while a low shock elicited prompt jumping from DBA mice but provided relatively weak motivation to avoid consistently. Nonetheless, the new strain differences were significant and of a magnitude similar to those observed under the equal shock condition.

Although not of primary concern, the effects of equating jumping on performance in one-way and optional training were informative as well. Values of estimated ω^2 , shown in Table VI, were derived from log total errors and log latency of the first escape for the equal shock and equal jump conditions. Equating for jumping reduced strain variation in total errors by about 24% in one-way training but gave no change in optional training, while it actually increased ω^2 of log latency of the first escape in one-way training. Between-strain variation in log latency for optional training was near zero under both shock conditions.

Table VI. Between-Strain Variation (ω^2) in Log Latency of First Escape (LFE) and Log Total Errors (TE) Under One-Way and Optional Training with Equal Shock and Equal Jumping

	Log (LFE)		Log (TE+1)	
	One-way	Optional	One-way	Optional
Equal shock	-0.001	0.046	0.340	0.113
Equal jump	0.172	-0.053	0.258	0.113

Thus equating for jumping produced only one substantial change in the magnitude of between-strain variation: complete abolition of genetic variation in latency of the first escape in jump-out training. Two important conclusions follow from this outcome. First, initial escape behavior has little to do with the rate of avoidance learning in any of three training procedures employed herein. For jump-out training, this follows both from the lack of consistent strain rank-ordering between latency of the first escape and total errors under the equal shock condition and from the discordant changes in ω^2 for the two variables. This conclusion also holds for one-way and optional training because there were no significant strain differences in latency of the first escape but large differences in total errors. Second, the strain differences in response to shock can be attributed to differences in response topography but not to sensitivity or motivational differences. Equating the strains for jumping reduced ω^2 for jump-out training but increased ω^2 for one-way training; that is, jumping was incompatible with running. When given a choice of escape route in optional training, the jumpers jumped and the runners ran with equal celerity.

One question is raised by these results which presents a fascinating puzzle for those who are prone to thinking about motivation, learning, and performance. Although equating jumping by giving different shock intensities to different genotypes did not abolish genetic differences in learning rate, there was, nonetheless, a monotonic relation between shock intensity and learning rate within a strain. Therefore, it should be possible to derive levels of shock for each strain which would yield equal learning rates. If this were done, then for what aspect of mice would one have actually equated: motivation, learning, both, or neither? Perhaps discussion of this question should be deferred until after the results of the second experiment have been presented.

EXPERIMENT 2

Whenever a correlation between a particular variable and rate of avoidance learning is observed for a limited sample of inbred strains, it is extremely important to evaluate the correlation in F₁ and segregating generations derived from these same strains in order to eliminate the possibility of a spurious correlation. Although a strong correlation between initial response to shock and rate of avoidance learning was not observed in Experiment 1,

similar measures in F_1 and segregating generations are nonetheless interesting because they can provide additional evidence for or against the independence of the two phenotypes. It is also possible that the homozygous substrate for the relevant genes in the inbred strains prevented or reduced the expression of a genetic as well as an environmental correlation between the two phenotypes. Thus for the sake of generality it is wise to test response to shock and avoidance learning in heterozygous and segregating populations derived from the inbred strains.

In the present experiment, mice from two F_1 hybrids and a four-way cross between the four inbred strains tested in Experiment 1 were given the sensitivity pretest and either jump-out or one-way avoidance training. No attempt was made to equate for the amount of jumping.

Method

Subjects

Twenty male and 20 female mice of each of the hybrid strains B6AF₁/J and B6D2F₁/J were obtained at 7 weeks of age from the Jackson Laboratory. The strain B6AF₁/J was a cross of C57BL/6J female with A/J male mice and B6D2F₁/J was from a C57BL/6J female mated to a DBA/2J male. In addition, 30 male and 30 female mice from the third generation of a four-way cross between the inbred strains A/J, CBA/J, C57BL/6J, and DBA/2J were tested. The heterogeneous population is maintained at the Waterloo laboratory through random mating with 16 breeding pairs per generation. The Ss receiving training were selected at random from 16 litters with the constraint that not more than one mouse of the same sex from any one litter could be assigned to the same testing condition. The strain designation for these mice was H3. All mice were maintained as in Experiment 1.

Apparatus

Equipment was identical to that employed in Experiment 1.

Procedure

The ages at testing of the strains B6AF₁, B6D2F₁, and H3 were 60, 59, and 55 days, respectively, with a standard deviation of 1.5 days. This involved a stay in the laboratory of about 1 week for the Jackson hybrids. The H3 mice, of course, spent their entire lives in the Waterloo laboratory.

Sensitivity Testing. The sensitivity pretest consisted of an ascending series of six different shocks of 2 sec duration followed by a descending series, as in phase 1 of Experiment 1. Shock was applied via a wound clip in the nape of S's neck, which was inserted during brief carbon dioxide anesthesia on the morning prior to testing. Recordings were taken of the current through S and the squealing during each shock, as in Experiment 1.

No resistance measures were taken, and no testing was done with the diode bridge shock scrambler employed in phase 2 before.

Sensitivity testing was administered to six Ss of each sex for the F_1 hybrid strains, while 12 Ss of each sex were tested from the H3 population.

Avoidance Training. All training was given with a shock intensity of 180 μ a as in the equal shock condition in Experiment 1. The procedures for jump-out and one-way training were identical to those in Experiment 1. Each S was trained to a criterion of five consecutive avoidances or until 50 trials were completed.

The numbers of Ss of each sex receiving jump-out training were 10, 10, and 12 for the strains B6AF₁, B6D2F₁, and H3, respectively; the corresponding number of Ss given one-way training were 4, 4, and 7. No optional training was given in Experiment 2.

Results and Discussion

The objective of the second experiment was not to compare the hybrid strains to one another but rather to their respective parent strains. The comparison of greatest interest was between the performance of a hybrid strain

and the mean of its parent strains (midparent score or MP). Since these were planned comparisons, *t* tests were used to evaluate the hypothesis that the hybrid mean did not differ from the midparent score. The error term was always the within-strain variance from the data in Experiment 2. The results for several variables of interest are given in Table VII, together with the appropriate midparent scores derived from the data in Experiment 1.

Table VII. Comparisons of Hybrid Scores to Midparent Score (MP) for Several Variables from Experiment 2

Measure	Strain					
	B6AF ₁	MP	B6D2F ₁	MP	H3	MP
Pretest						
Actual current at 180 μ a	176.5	174.3	166.5	174.7	177.0	174.9
No. of jumps at 180 μ a	3.2	4.5	5.6 ^a	8.4	3.6 ^a	5.4
No. of squeals at 180 μ a	8.1	6.1	10.2 ^b	6.0	5.2	4.8
Jump-out						
LFE	12.6	12.3	6.8	7.1	9.0	10.1
TE	10.2 ^c	16.4	9.8	12.4	9.8 ^a	12.7
One-way						
LFE	7.0	10.0	11.0	11.2	9.8	10.1
TE	14.9 ^c	30.2	8.6 ^a	14.5	10.8 ^c	26.6

^a Significantly different from midparent with $p < 0.05$.

^b $p < 0.01$.

^c $p < 0.001$.

In the sensitivity, pretest, there was generally less jumping and more squealing than in Experiment 1. The difference in jumping between the hybrid and midparent scores was marginally significant for the B6D2F₁ and H3 strains, while squealing was significantly greater only for the B6D2F₁ mice. Since the jumping and squealing measures changed in opposite directions, the results cannot be attributed to a change in general sensitivity to foot shock.

Results from avoidance training, midparent scores from Experiment 1, and significance levels are given in Table VII. It is clear that the small differences in responses to shock during the pretest were not reflected in escape behavior on the first training trial, for in no case was the latency of the first escape significantly dissimilar for any hybrid strain and its midparent. In several instances, the hybrid mean was very close indeed to the midparent score. Only the strain B6AF₁ appeared to differ from MP in one-way training; however, the difference did not approach significance ($p > 0.10$).

The total errors to achieve the learning criterion of five consecutive avoidances generally were significantly fewer for the hybrids than for their inbred parents under both jump-out and one-way training. The only exception was the strain B6D2F₁ under jump-out, where the difference failed to achieve an acceptable level of significance ($t = 1.67$, $df = 19$, $p < 0.10$). Comparisons of each hybrid with the parent having fewest total errors revealed that the B6AF₁ strain was significantly superior to its parent strain C57BL/6 ($p < 0.01$) in jump-out training; no other comparison even approached significance (all $p > 0.10$).

Altogether, the data from Experiment 2 pointed to different modes of inheritance for response to shock and rate of avoidance learning. The loci affecting latency of the first escape were generally characterized by intermediate inheritance. Similar intermediate inheritance was evident for several measures in the sensitivity pretest. The strains whose initial jumping contraindicated intermediate inheritance actually jumped less than the average of their parent strains. On the other hand, total errors in avoidance learning exhibited significant dominance in five out of six comparisons. Four of these five instances suggested complete dominance at the presumed heterotic loci, while one comparison revealed significant overdominance. Thus, in the strains of mice examined in these experiments, inheritance of initial response to electric shock was of an intermediate nature, while a measure of avoidance learning revealed dominance to be the rule.

The lack of relation between initial escape behavior and avoidance learning was also evident from comparisons between hybrid strains. The strain B6D2F₁ escaped more quickly than B6AF₁ under jump-out training ($F = 5.4$, $df = 1/82$, $p < 0.05$), while strain B6AF₁ was faster under one-way training, although the latter difference was not significant ($F = 2.6$, $p > 0.10$). However, no significant differences in total errors were detected for either strain, training condition, or their interaction (all $p > 0.20$).

Similar results obtained within strains. The correlation between log latency of the first escape and log total errors in jump-out training was not significant for either strain B6AF₁ or B6D2F₁ ($p > 0.10$), but it was marginally significant for the H3 strain ($r = 0.35$, $df = 23$, $p = 0.05$). If it can be assumed that environmental sources of covariation between initial escape behavior and learning rate were the same for the two hybrid strains and the heterogenic H3 strain, then it follows that the genetic correlation between them was greater than zero. Unfortunately, the precise magnitude of the genetic correlation cannot be determined from a comparison of isogenic and F₃ populations. Whatever the true genetic correlation, it led to a phenotypic correlation that could account for only 10% of the observed variation in log total errors.

However, it is possible for escape latency to show intermediate inheritance and for learning rate to show dominance but still to find a very large genetic correlation between them. The reason for this is simple; genetic correlation in a heterogeneous population measures the correlation only between additive genetic components. If all the loci which modify escape latency similarly affect learning rate, then the genetic correlation will be quite large. There may also be loci which affect learning rate and show dominance or overdominance but which do not modify escape behavior. If the set of genes which affect escape latency is a proper subset of the set of genes which affect learning rate, then the above results could easily occur. On the other hand, it is equally possible that the relevant loci are the same for both measures but that the genes affect escape latency mechanisms additively while manifesting dominance for rate of learning (see discussion by Lerner, 1954). Clearly, this possibility needs to be studied with the more reliable parent—offspring regression techniques discussed by Falconer (1960).

CONCLUSIONS

The present experiments provide strong evidence that, using certain testing procedures and strains of mice, there is little or no relation between the initial response to electric shock and the rate of learning several avoidance tasks. In Experiment 1, this outcome was evident from the dissimilar strain rank-orderings between latency of the first escape and total errors in avoidance training, as well as from the failure of the equated jumping manipulation to eliminate between-strain variation in total errors. Experiment 2 revealed that the initial response to shock exhibited intermediate inheritance, while avoidance learning was characterized by complete dominance when averaged across the several presumed loci modifying the learning phenotype.

Given the validity of the above conclusions, it is important to consider the generality of these findings to other genetic backgrounds. The strains employed in these experiments were not a random sample of inbred strains; in fact, they were chosen to represent different degrees of vigor of the initial reaction to shock. A recent report by Rose and Parsons (1970) suggests that other strains may behave similarly, however. Using a barrier-crossing avoidance task and the strains BALB/c/An, C57BL/Ka, and C3H (subline unspecified), they found dissimilar strain rank-orderings between the initial reaction to shock and learning rate. Thus the conclusions appear to apply to a broad range of the commonly used inbred strains, including A, BALB, CBA, C3H, C57BL, and DBA. In both the present study and that of Rose and Parsons, a single strain was responsible for the dissimilar rankings, CBA in the former and C3H in the latter experiments. This points out a limitation of experiments with inbred strains. Since each strain represents only one genotype replicated many times, even a rather ambitious inbred strain study examines relatively few genotypes compared to a study of a heterogeneous population. Perhaps there is a relation between initial response to shock and avoidance learning for a majority of the commonly studied strains. What has been shown, to be sure, is that the kind of relation depends upon the genotype. Of course, the present study also demonstrates the usefulness of inbred strains when one wishes to measure two characteristics of a genotype, but the act of measuring one changes the score of an *S* on the other. The operation of equating jumping of various genotypes is uniquely suited to inbred strains.

One aspect of the above strain differences which should be followed up is the extent to which the differences are manifestations of two deleterious genes, albinism (*c*) carried by A/J and retinal degeneration (*rd*) carried by CBA/J. The pleiotropic effects of albinism attributable to an adverse reaction to intense light (see Wilcock, 1969) are not expected herein, since a dim red light was used, but there may be other visual system abnormalities which influence the learning phenotype (e.g., Lund, 1965). It probably does not influence strongly the latency of the first escape, for that measure showed intermediate inheritance in the B6AF₁ hybrid strain. However, the learning measure may well have been strongly affected by albinism, much as was reported by Henry and Schlesinger (1967) for jump-up avoidance learning. Retinal degeneration certainly does not disrupt all avoidance learning, since strains with this defect were observed to learn most quickly in jump-out training in this study and in barrier-crossing training by Rose and Parsons. Nonetheless, the poor performance on one-way avoidance reported above for CBA may reflect the poor eyesight from the *rd* gene. Although mice with *rd* have rudimentary sensitivity to light (Bonaventure and Karli, 1961), the adults appear to possess little or no pattern vision (Frank and Kenyon, 1966). Thus they may be able to jump out of a box with ease but still have difficulty finding a small hole in the wall under dim illumination.

The modes of inheritance of initial response to shock and of avoidance learning warrant further examination. Although the present study detected intermediate inheritance of the latency of the first escape, one other study has reported heterosis for escape from aversive stimulation (Rose and Parsons, 1970). These two outcomes may perhaps be attributable to the different strains and F₁ hybrids studied. In a study of shock-elicited activity in mice, Newell (1970) reported that F₁ hybrids from certain strains exhibited only additive effects, while other crosses revealed incomplete dominance and epistasis. There appears to be general agreement, however, that avoidance learning is characterized by either complete dominance or heterosis (see Collins, 1964; Schlesinger and Wimer, 1967). As mentioned in the presentation of results for Experiment 2 above, further study of these behaviors should be done with a heterogeneous population.

Another problem raised by the above experiments is the generality of genetic differences in avoidance learning ability across different training procedures. It is clear that the required response is a very important determinant of performance for certain strains, such as A and CBA, while others, such as DBA/2, appear to be proficient under a variety of procedures. These findings raise the question of the relative importance of general and task-specific abilities in laboratory mice. The so-called general learning ability has often been considered to be synonymous with intelligence for both rats (Thompson, 1954) and humans (Jensen, 1969). Although the present results say little about the intelligence of various genotypes, they do lead to some thoughts about how to measure general learning ability. The genetic correlation (r_A) between learning scores on two different tasks measures the proportion of genes (additive effects only) which influence both learning phenotypes. If r_A is small or negative, then it follows that the demands of the specific task are of critical importance. On the other hand, if r_A approaches 1.0, then the two tasks must involve many genes in common. These measures can be obtained best in a heterogeneous population using regression methods or index selection (Falconer, 1960, p. 324).

The importance of task-specific response abilities may be even greater when different species are compared. A case in point is the deer mouse, *Peromyscus maniculatus*. The arboreal *gracilis* subspecies acquired a pole-climbing avoidance response more quickly than a running response (Wolf *et al.*, 1962), while the terrestrial *bairdi* subspecies was more proficient at running than at climbing to avoid shock (Cole and Wolf, 1969). Furthermore, the preferred response mode was generally modified less by drugs than the more alien alternative response. Bolles (1970) has recently discussed the importance of response requirements for studying the laws of learning. He demonstrates that the effect of an independent variable can be quite different when the correct avoidance response is an element of the set of "species-specific defense reactions" than when it is something that an animal normally does not do during pain, such as pressing a bar. The implications of these notions for the broader study of learning have been cogently presented by Seligman (1970). One conclusion is apparent from the papers by Bolles and Seligman: Response capabilities and/or preferences are not simply peripheral contaminants which tend to obscure the genuine laws of learning, but rather they are crucial determinants of those very laws. The present study adds to their discussions the probability that response differences are present *within* a species in the form of an interaction between the genotype of the subject and the type of training

procedure. One advantage of strain studies over species comparisons, however, is that the former are amenable to experimental analysis by cross-breeding or selection, while the latter are confined to conjecture and nature stories.

Finally, it is appropriate to discuss the relation between motivation and learning as it applies to shock avoidance learning. Motivation is a concept which deals with the conditions required to evoke performance of a response that has been learned previously. Whether motivation is also required to allow learning to occur in the first place is a question surrounded by controversy, partly because of the various theoretical formulations adhered to in the past and partly as a result of the serious difficulty in obtaining independent measures of motivation and learning. This latter problem can be seen very clearly in the present experiments. Neither running nor jumping alone can measure the motivation provided by a particular shock, since different strains emit different initial responses; squealing measures are beset by similar difficulties. It seems that electric shock confounds most efforts to measure directly its motivative powers because, unlike thirst, hunger, or sexual motives, shock directly elicits intense skeletal responses. Given this problem, perhaps the wisest course for future research would be to employ a transfer test to determine what a particular strain has learned after a specified amount of avoidance training. By testing performance under different levels of shock following initial training with other levels of shock, it should be feasible to measure what was learned (see discussion by Kimble, 1961, Chapter 13). This strategy will entail experiments of considerably greater behavioral sophistication than those conducted in the past by giving but a single kind and amount of training to animals of different genotypes.

In conclusion, it should be emphasized that the bases for genetic differences in the rate of shock avoidance learning are still unknown. The present experiments suggest strongly that genetic differences in the initial response to shock, which are themselves quite substantial, do not contribute significantly to the genetic differences in avoidance learning.

These experiments also suggest instances in which the aforementioned relationship may in fact obtain. Since significant strain differences in resistance before and during shock were detected, it follows that differences in the amount of current drawn by various strains will be large whenever a low-voltage shock source is employed (Ohm's law), such as the 60 v supply used by Rose and Parsons; a method like theirs should magnify strain differences in learning rate. Of course, differences in skin resistance can be overcome through the use of a high-voltage, constant-current shock source. Furthermore, the differences in initial response to shock may be important if the task in question is typically learned in very few trials, as in the popular inhibitory step-through task. Strains which require several trials to acquire the appropriate escape response will then achieve the criterion of "avoidance" learning more slowly than strains which escape proficiently on the first trial. Once the proper escape response is acquired, however, factors other than the mode of initial response to shock become important as determinants of learning rate. If the initial escape learning constitutes a relatively small proportion of the total trials to achieve criterion, then initial escape behavior will have little influence on the total error score. Thus the influences of genuine strain differences in sensitivity and response topography to electric shock upon the rate of avoidance learning should be effectively eliminated by incorporation into the experiment of a shock source of proper design and a training procedure in which learning to anticipate the shock requires considerably more trials than does learning to escape the shock.

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