STIMULUS GENERALIZATION OF GRAVITY¹

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In two experiments, squirrel monkeys were exposed to centrifugally generated, artificial gravity and trained to respond for food reinforcement at selected gravity (*g*) levels. Experiment I involved a single *g* value; in Exp. II, subjects were trained to discriminate among two or three *g* values. After training, generalization tests were administered over a 1.1-*g* to 2.1-*g* range. The major findings were as follows: (a) single-stimulus training yielded a linear relationship between percentage of responding and magnitude of gravity. (b) Two-valued discrimination training produced gradient peaks which were shifted from *S*^D in a direction away from *S*^A. This effect was cancelled when *S*^D was located equidistant between two *S*^A stimuli. (c) Gradient form was independent of the *S*^D-*S*^A difference, but related to continuum location and/or intensity of discriminative stimuli.

Gravity is among those conditions which provide stimuli to all organisms on earth. Previous experimental work with the gravity dimension has focused upon measuring various physiological responses and tolerances in organisms exposed to space flight and to dynamically simulated gravities (*e.g.*, Wunder, 1966; Oyama, 1965). However, the behavioral effects of different levels of gravity and variations of gravity have been relatively unexplored.

Clearly, a thorough analysis should examine the role of gravity and consequent body weight in the control of behavior. For example, weight stimuli may possess reinforcing and discriminative properties. The present research explored this possibility, utilizing the classical technique of stimulus generalization. The experiments involved the centrifugation of squirrel monkeys. The stimulus dimension was centrifugally generated, artificial gravity producing a weight range of 1.1 to 2.1 times normal earth weight (*i.e.*, 1.1 *g* to 2.1 *g*). Differential magnitudes of this variable were presented during subsequent generalization tests.

¹This research was supported by Grant Ns G-456 from the National Aeronautics and Space Administration. Reprints may be obtained from D. F. McCoy, Wenner Gren Aeronautical Research Laboratory, University of Kentucky, Lexington, Kentucky 40506. The authors wish to express their gratitude to Craig Love and Connie Roberts for aid in running the subjects. We are particularly indebted to Eliot Hearst for his helpful comments.

EXPERIMENT I

The first experiment sought to ascertain whether generalization gradients could be obtained without explicit discrimination training. Reinforcers were obtainable at one gravity level only, but discrimination training, as such, was not attempted.

METHOD

Subjects and Apparatus

Five adult male squirrel monkeys (*Saimiri sciurea*) were housed in individual cages and maintained at 85% of free-feeding weight throughout the experiment.

Figure 1 shows the main apparatus, a constant-radius, variable-speed centrifuge. Figure 2 shows a subject restrained inside the capsule mounted on one arm of this centrifuge at an effective radius of 1.6 m. As Fig. 1 indicates, the capsule was free to pivot so that the effective weight during rotation (*i.e.*, the resultant of earth weight and centrifugal force) always acted along the spinal axis of the subject. The effective weight of the subject over the range of 1.1 *g* to 2.1 *g* was changed by varying the rotational speed between 15.6 and 31 revolutions per minute. Such changes always took place at the rate of 1 *g* per 30 sec to minimize the accompanying acceleration in the tangential direction.

Centrifugation is the only means by which increased gravities can be produced for prolonged periods of time, and rotation is a nec-

Fig. 1. Animal capsule mounted on the centrifuge. Major components of the centrifuge are labeled. The capsule is tilted as it would be during rotation. The capsule is pivoted and balanced so that it maintains the same orientation to the direction of the resultant force at all angular velocities. The three arrows indicate hypothetical vectors for the gravitational (W), centrifugal (C), and resultant (R) forces.

essary part of centrifugation. It is an artifact of centrifugally produced gravity that does not exist in real gravity. Moreover, centrifugation simulates real gravity without additional side effects only if the organism is immobile relative to the centrifuge. The mathematical relations for translating rotational motion into resultant forces appear in most textbooks on classical physics or mechanics (*e.g.*, Den Hartog, 1961).

Figure 2 also shows a retractable lever mounted on the capsule wall directly in front of the subject. A response was defined as a release of this lever, and each response produced a relay click audible above the constantly present 85-db white noise. This intensity was sufficient to mask possible auditory cues provided by differential rotation speeds. Accelerometer measurements indicated that vibration of the centrifuge was minimal and constant for all speeds. A standard Foringer pellet dispenser was mounted on top of the capsule and 97-mg sucrose pellets were delivered through a copper tube extending into the capsule interior. The capsule was illuminated by two 5-w fluorescent lights. No visual contact with the external environment was possible when the subject was sealed within the capsule. Continuous observation of the subject was provided by a closed-circuit

Fig. 2. View of monkey restrained in the centrifuge capsule. The subject is facing the axis of rotation. The response lever is located directly in front of the subject.

TV system. Electrical communications with the centrifuge were provided by a slip-ring assembly. Standard electromechanical equipment was used to schedule and record events.

Procedure

After attaining the proper deprivation level, subjects were assigned to specific treatment conditions in terms of the effective weight at which lever responses were to be reinforced; *i.e.*, the S^D . Subjects 17 and 38 were trained at 1.3 g; Subjects 05, 21, and 33, at 1.7 g.

Preliminary training consisted of exposing the subjects to S^D centrifugation for three 1-hr sessions to dissipate any symptoms of nausea (*e.g.*, vomiting) produced by head movements and excessive activity in the rotating environment. The incidence of such activity subsided rapidly and all subjects promptly learned to maintain a fixed head position during centrifugation. Therefore, it did not seem necessary to fix the head position by artificial means. The subjects then received three days of magazine training at the S^D level. During the next three sessions, the lever was made available and each response reinforced. These

sessions were terminated after 1 hr or 50 reinforcements. Next, a variable-interval schedule with a mean interreinforcement interval of 1 min (VI 1-min) was introduced. At this point, the duration of stimulus presentations was reduced to 1 min, followed by a timeout.

During the timeout, the artificial gravity, and consequently the weight of the subject, was changed away from the S^D value and then returned to it without pausing at any other gravity level. Direction and magnitude of these excursions were mixed, but the change always took place at the rate of 1 g per 30 sec. Thus, timeout duration depended upon the respective distance along the g-continuum from the S^D value. It varied from 4 to 20 sec. During timeout, the houselights within the capsule were automatically switched off and remained off for the duration of the timeout interval. The timeout procedure was intended to prepare the animals for generalization testing by ensuring that responses to the test stimuli would not be confounded with possible stimulation by the tangential forces necessary to produce the test stimuli, notwithstanding the fact that the tangential acceleration amounted to less than 1/100 g at the aforementioned rate of gravity change.

One-hour sessions were provided daily until 25 sessions of VI training had been completed. By this time, timeout responses were less than 20% of S^D responses for all subjects. Generalization tests were administered on Day 26. One-minute exposures to six generalization stimuli (1.1 g, 1.3 g, 1.5 g, 1.7 g, 1.9 g, and 2.1 g) were provided in mixed order and separated by a timeout. Each stimulus was presented 10 times. Responding was not reinforced.

RESULTS AND DISCUSSION

Relative generalization gradients for the individual subjects appear in Fig. 3. The angular velocities corresponding to each g value presented are also indicated. As Fig. 3 shows, the major purpose of the experiment was fulfilled: responding changed substantially and systematically with variations in g. Furthermore, the increased responding associated with higher g-levels was, with minor exceptions, common to all subjects. Slight deviations occurred with Subjects 21 and 33. Monkey 21 peaked sharply at 1.9 g and produced considerably fewer responses in the 2.1 g condition. This effect proved to be quite

replicable during subsequent testing with the same subject. Subject 33 evidenced little differentiation in the range below the 1.7 S^D , but a sharp increase in responding to all higher g values. Steepened gradients below the S^D were also produced by Subjects 17 and 38, trained at 1.3 g. Still, the general form of these functions appears to be independent of S^D magnitude. No systematic relationship between S^D intensity and gradient slope is revealed by the individual gradients in Fig. 3 or by the combined data for each S^D treatment. However, a wider range of S^D values needs to be studied before a firm conclusion can be drawn.

The asymmetry of gradients reported here resembles the findings of Hoveland (1937) and more recently, Hearst (1968) with auditory intensity. Such upward-sloping gradients have been referred to as *descriptive* stimulus intensity dynamism (Gray, 1965). Perhaps the present results are attributable to stimulus intensity; however, other possible sources of stimulus control must be considered.

It is conceivable that certain methodological artifacts resulted from the timeout feature. For example, it is possible that some discrimination training developed as a result of this procedure and that responding was extinguished to all g values other than the S^D . However, it was to guard against this possibility that operation of the houselights was paired with changes in rotational velocity during timeout. Subsequent tests at 1.0 g (zero rpm) indicated that lever pressing was under the control of the houselights. Notwithstanding, if g discriminations had developed during training, it is puzzling why the subsequent generalization gradients did not peak at the S^D . Furthermore, if the upward-sloping gradients resulted from implicit discrimination training during timeout, then differential amounts of S^A training must have been given to the various test stimuli. This was clearly not the case, inasmuch as the frequency of approach to each test stimulus was balanced for every training session. Finally, it seems unlikely that visual and/or auditory artifacts could be responsible for the present findings. As previously pointed out, stimulation of these modalities was either absent or constant for all rotational speeds.

The results indicate that single-stimulus training produces gradients peaked away from

Fig. 3. Percentage of responding as a function of g magnitude for S^D -only training. The angular velocities associated with each g value are shown. S^D values are indicated.

S^D . A question then arises concerning the sensitivity of gravity generalization gradients to other kinds of manipulations. For example, can stimulus control be increased, and will gradient shape be altered as a result of explicit discrimination training? Experiment II dealt with some of these problems.

EXPERIMENT II

The steepness of a generalization gradient is presumably an index of the degree of stimulus control exercised by the relevant dimension. However, gradient steepness depends upon the type of training given as well as the modality studied. The major purpose of Exp. II was to determine whether techniques which yield known effects with more conventional stimuli also produce these effects with artificial gravity.

METHOD

Subjects and Apparatus

Eight adult male squirrel monkeys were used; six were experimentally naive and two were continued from Exp. I. One animal died in the course of training and no generalization data were gained from it. Housing and deprivation conditions were the same as in Exp. I. The apparatus was as described earlier.

Procedure

The naive subjects were distributed over the four training conditions depicted in Fig. 4. Subjects 33 and 38 were assigned treatments having the same respective S^D as in Exp. I. It seemed likely that the introduction of S^A training might produce an increased response rate to S^D (i.e., behavioral contrast; Reynolds, 1961) with these subjects.

STIMULUS PRESENTATIONS

Fig. 4. Diagram of the four training conditions studied. The subjects trained under each condition are indicated. Monkey 35 died during training.

To facilitate later discussion, all two-valued training procedures will be referred to hereafter with two numerical values; the first value designating the S^D and the second, the S^A . The principal features of the experiment are shown schematically in Fig. 4. First, S^A is the higher intensity stimulus in each of the two-valued discrimination procedures. This was intended to reverse the nearly linear relationship between g magnitude and response strength seen in Exp. I. Secondly, S^D and S^A were situated 0.4- g apart in the 1.3 g -1.7 g condition and in the 1.7 g -2.1 g condition. Since the S^D - S^A differential was constant, any disparities in gradient form could be attributed to other factors. Thirdly, two conditions involved the same S^D (1.3 g), but S^A s of different magnitudes (1.7 g or 2.1 g). Comparison of the resulting gradients would indicate the importance of the absolute intensity between S^D and S^A stimuli. Finally, for two subjects, S^D was placed at the midpoint of the continuum with an S^A situated at each extreme. The significance of S^A location could then be evaluated on a within-subject basis by comparing the gradient slope on each side of S^D .

All subjects were given the preliminary training of Exp. I. Discrimination training

began simultaneously with the initiation of the VI 1-min schedule. Subjects 33 and 38 were placed on discrimination training after the generalization test of Exp. I.

In the two-valued discrimination conditions, simple alternation between S^D and S^A stimuli was avoided by presenting the stimuli equally often, but in a mixed order with a maximum of three consecutive presentations. In the three-valued treatment, order of stimuli was also mixed, but each S^A was presented half as often so that the combined total of S^A presentations equalled that of S^D .

Stimulus intensity was changed by varying the rate of rotation of the centrifuge (as in Exp. I) until the desired g level was attained, then maintained for the 1-min duration of stimulus exposure. Stimulus presentations were separated by a timeout. Where successive presentations of the same stimulus were scheduled, the timeout consisted of a gravity change away from, and a subsequent return to the former value, as in Exp. I. Again, the capsule was darkened during timeout accelerations. Responses occurring during transition were recorded as timeout responses.

Sessions of approximately 1-hr duration were provided daily until S^A responses were less than 15% of S^D responses for three consecutive days. Generalization tests were then given on the next day. The number and sequence of stimuli presented were identical to Exp. I except for the 1.6- g condition included for Subjects 13 and 32, trained on the three-valued discrimination.

RESULTS AND DISCUSSION

All subjects reached criterion within 42 sessions of VI training. No systematic relationship appeared between specific training conditions and number of sessions required to reach criterion. Of the naive animals, Subjects 39, 04, 13, 34, and 32 required 27, 29, 34, 35, and 42 sessions, respectively. Subjects 33 and 38 trained considerably faster, requiring 17 and 20 sessions, respectively. Rate of S^D responding increased for both of these subjects over the terminal rate in Exp. I. However, this increase was moderate compared to that reported by Reynolds (1961) and Terrace (1966); S^D rates increased 43% and 51% for Subjects 33 and 38. This increment was fully developed by Session 3 and maintained throughout training.

Fig. 5. Generalization functions for five individual monkeys trained under two-valued discrimination procedures. S^D and S^A values are indicated. Points are plotted as a percentage of total responses during testing.

Figure 5 shows the relative generalization gradients for subjects trained under the two-valued discrimination procedures. Clearly, discrimination training was effective in overriding the increasing functions of Exp. I. This result is particularly impressive in the case of Subjects 33 and 38, for which a decided change in gradient shape was effected through S^A training. Furthermore, a displacement of the maximum point from S^D away from S^A is common to each gradient. This peak-shift phenomenon is usually reported for the visual modality, but the present findings, along with those of Pierrel and Sherman (1960, 1962), indicate that it is not restricted to visual, or for that matter, nonintensive continua.

The location of S^D and S^A along the g-continuum apparently was more a determinant of gradient shape than S^D - S^A intensity differential; responding was inversely related to g magnitude when S^D was 1.3 g, and the general form of the gradient was unrelated to S^A intensity. Subjects 34 and 38 (upper half of Fig. 5) yielded linearly decreasing functions in the S^D - S^A region. Despite a greater S^D - S^A differential, Monkey 39 produced a similar, although somewhat steeper, gradient between 1.3 g and 1.7 g. The importance of stimulus location is further underscored by comparison of the 1.3 g-1.7 g and 1.7 g-2.1 g gradients. Although S^D - S^A differentials were equal, the latter condition uniquely produced bidirectional

Fig. 6. Generalization gradients for two subjects trained under the three-valued discrimination procedure. Points are plotted as in Fig. 3 and 5.

tional functions. With respect to S^D, the gradients are still asymmetrical, inasmuch as responding on the S^A side was consistently lower than responding at comparably distant points to the left of S^D. These results resemble those of Pierrel and Sherman (1960) and support the conclusion that gradient form was a joint function of S^D-S^A stimulus control and position of the stimuli along the g-continuum.

Unlike the Pierrel and Sherman experiment, the data in Fig. 5 provide no information on the importance of intensity, *per se*. That is, while the effect of the 1.7 g-2.1 g condition on gradient shape was presumably due to the differential location of S^D and S^A on the g continuum, this treatment also involved higher intensity stimuli. It is possible that the greater absolute intensities tended to counteract the effect of S^A at the 2.1 g location and flatten gradients in this region.

The results of the three-valued discrimination training shown in Fig. 6 shed some light on this possibility. Relative to the two-valued condition, this treatment produced sharper and more symmetrical gradients. The absence of peak shift is noteworthy, both gradients reaching maximum at the S^D value. Stimuli

more intense than 1.6 g were responded to more than were comparably distant values below 1.6 g. Accordingly, gradients to the left of S^D fall off in an orderly manner and assume a concave function, while the right sides appear somewhat skewed and considerably flatter. This finding suggests that stimulus differentiation is more difficult when S^A is of a higher intensity than S^D; it is also consistent with the findings of Sadowsky (1966), who reported that responding was elevated in the presence of higher intensity S^A stimuli. This effect is also evident in Fig. 6.

The results of Exp. I and II indicate that artificial gravity, as here produced, exhibits many of the properties of more conventional discriminative stimuli. Gravity, or weight (*i.e.*, the product of resultant gravitational acceleration times the subject's mass), is specified as the independent variable because it is this factor which produces the pronounced physical and physiological effects (*i.e.*, force) in the organism. Still, angular velocity was the variable directly manipulated, and because the monkey was free to move its head relative to the centrifuge capsule, it is possible that the differential effects of such activity at different

rotational speeds were responded to by the subjects. From this viewpoint, it is conceivable that the present generalization gradients reflect differences in vestibular stimulation produced by variations of angular velocity, rather than artificial gravity. However, this hypothesis requires that head movements did occur, and systematically so with variations in angular velocity. Yet, it was previously pointed out that the effects of such head movements are highly aversive in that they often produce nausea and vomiting. It was for this reason that all subjects were exposed to centrifugation before training, and presumably why the animals learned to maintain a fixed head position throughout later experimental sessions.

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Received 31 May 1968.