Cross-modality matching of brightness to loudness by 5-year-olds¹

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The purpose was to determine whether 5-year-old children could match the brightness of a light to the loudness of a sound, and whether the resulting cross-modality function resembled the power function produced by adults. Each of five children adjusted the voltage on a 150-W lamp to make the apparent brightness appear equal to the loudness of a 500-Hz tone, which the E set to eight different levels. The results resembled those of five adults who performed the same task.

Although the power law seems to describe the relation of the physical stimulus to the perceived sensation in adults, the basis of the power relation remains open to question. One possibility is that the mechanism underlying the power function resides in the nature of the sensory transducers. Thus a transducer like the eye, following a nonlinear power law, may provide the mechanism that is needed to handle an enormous stimulus range and at the same time provide invariant ratio similarities in the visual field. For example, Yilmaz (1967) sees the evolutionary adaptation of the transducers as the basis for the nonlinear transformations needed to couple some of the wide-ranging environmental variables to the more linear systems within the central nervous system.

An alternative view is that the power law is learned, being built up from experience with stimuli for which veridical judgments are readily made, a kind of stimulus-error theory (Boring, 1921). Thus, Ebbinghaus (1890) suggested that judgments of brightness are based on a person's having seen a room lighted by one candle and by two candles. Warren (1958) formulated a similar kind of stimulus-error theory, except that subjective brightness, he said, is based on distance judgments combined with a person's observation of the inverse-square law governing light intensity. The S would presumably have seen a light placed at a distance that appeared to be twice as far away as on some previous occasion and would have noted the attenuation of the illumination. The conjunction of such observations would then determine the S's response to luminous intensity in a scaling experiment. If the inverse-square experience determines the outcome, the exponent of the power law for brightness would be 0.5 (provided the exponent for distance is 1.0). If Ebbinghaus's multiple sources determine the brightness function, the exponent for brightness would be 1.0. Actually, the consensus of numerous experiments suggests that the brightness exponent is approximately 0.33.

Decisive evidence for either theory—evolutionary adaptation of transducers or learning through the utilization of veridical experiences—is not easy to obtain. Nevertheless, if the relation of sensation to stimulus depends more on learning than on transducers, we may suppose that the relation ought to differ in children and adults. In other words, it becomes important to determine psychophysical functions at early ages.

Dorfman and Megling (1966) carried out a scaling experiment with 20 children (9.9 to 11.9 years). The children made magnitude estimations of loudness, and the results were compared with those of a group of 20 adults who made similar judgments under the same circumstances. The comparison

showed that both children and adults judged loudness according to similar power functions. That result is interesting, but not too surprising. Ten-year-olds have usually had much experience with the physical world and with simple mathematical relations.

The present experiment sought to push the problem back to an earlier age and to see whether cross-modality matching between two sensory continua would make it possible for young children to report their sensory impressions without having to use numbers.

METHOD

Subjects

The 5-year-olds were mostly children of members of the Harvard Psychology Department. One was the child of a friend of a department member. For the procedure finally followed, five children were selected out of the eight who were tested. Those not selected were children who in the preliminary testing proved either too shy or too prone to distraction or preoccupation. The children who completed the task ranged in age from 4 years 2 months to 5 years 8 months, with an average of 5.0 years. The control group of five adults were students who had previously served in one or another kind of scaling experiment, although none had previously matched brightness to loudness.

Apparatus

An oscillator (General Radio 1309) generated a tone of 500 Hz, which was presented to the Ss through a set of earphones (Grason-Stadler D30). These earphones proved to be light enough for children to wear comfortably. The level of the tone was controlled by an attenuator.

An ordinary 150-W light bulb was mounted in a large 10-in. reflector, which was covered by a translucent sheet of milk Plexiglas. A 10-in. circular hole in a large sheet of black cardboard was centered over the light. The S controlled the voltage to the light bulb by means of an autotransformer, a Variac (General Radio 200 CM), whose calibrated dial was obscured from view. Several autotransformers were tried in order to find one whose action was very smooth and easy for the child to operate. The voltage was read by means of a voltmeter (Ballantine 300). The S sat approximately 3 ft from the stimulus source in a laboratory room that was lighted from overhead by recessed fluorescent lamps. With the room lights on and the stimulus lamp off, the luminance of the Plexiglas screen was 2 mL, or 73 dB re 10⁻¹⁰ L, as measured with a Macbeth Illuminometer. With the stimulus lamp off, the Plexiglas screen was at about the same luminance level as the walls of the laboratory room. Turning up the voltage made the stimulus lamp glow red-orange at first, and then more white. The red-orange color had the advantage of making the target distinctive and more easily attended to. The maximum stimulus luminance available was about 103 dB. In the process of calibrating the apparatus, the relation between voltage and luminance was found to be $L = kV^{3.7}$. That power function is consistent with values given in engineering handbooks (cf. Moon, 1961).

Fig. 1. Median cross-modality matches of brightness to loudness by 5-year-olds and adults. The voltage on a 150-W lamp was varied to produce brightnesses that appeared as intense as the loudnesses of a 500-Hz tone heard through earphones. The vertical lines show the interquartile ranges.

Procedure

Several procedures were attempted before the cross-modality matching of brightness to loudness was chosen for the task. One procedure was the matching of height to loudness. The child was asked to judge the loudness and make a mark on the wall that was as high as the sound was loud. It was found that the marks tended to be bunched into three ranges: near the ground, waist high, and head high. This procedure was tried with a 5-year-old and an 8-year-old, but both showed the same kind of bunching.

A modification of the task was tried in which the child was asked to move a block along the edge of a table and to use the distance from one end of the table as his continuum. Here again the children lumped the judgments into three categories. They also seemed overly aware of the far end of the table.

A cross-modality matching of brightness to loudness was found to be clearly easier for the children. They were told to adjust a light so that it looked as bright as the sound was loud. A few suggestive examples were given, e.g., "If the tone is really loud, you would turn the light way up" and then the E would turn up the Variac dial. "What would you do if the tone were very soft?" The child would usually turn the dial to a low value. If a child made the light very bright when asked what to do with a soft tone, he was usually asked whether this was what he really thought, or asked what to do if given a loud tone. Such guidance and suggestions helped the child to establish the criterion for success in the task. The children were frequently praised for their performance before the presentation of a tone rather than just after a match had been made. This type of reinforcement seemed to work quite well. In addition, they were all promised candy if they participated in the experiment.

As soon as the child seemed to grasp the nature of the task, the tones were given at eight different levels, 40-110 dB, presented twice each in random order. The children had no trouble sitting through the entire experiment and they made their adjustments of the light rapidly. A parent was often in the experimental room, which was relatively quiet but not soundproof.

When the adult Ss were run they were told simply that the

experiment was a cross-modality matching task in which they were to adjust the light so that it was as bright as the sound was loud. They were given the same set of stimulus tones as the children.

RESULTS

In Fig. 1 the medians of the voltage settings for children (circles) and adults (triangles) are plotted in log-log coordinates against the sound pressure level of the 500-Hz tone. For the purpose of clarity, the circles have been displaced 3 dB to the left. The median of the 10 matches for each sound made by the five children corresponds fairly closely to the median of the 10 matches made by the five adults. The data indicate that the growth functions for loudness and brightness are probably quite similar in the two groups of Ss.

As shown by the vertical lines through the medians in Fig. 1, the children (dashed lines) were only slightly more variable than the adults (solid lines). The vertical lines show the interquartile ranges of the raw data, with no attempt made to remove the intercept variability, i.e., the tendency of one person to set the lights to higher values and another person to lower values. The median interquartile range for the adults is 0.127 log unit and for the children, 0.161 log unit.

Geometric means were also calculated and there was no systematic difference between them and the medians. The medians were used for Fig. 1 because, at the upper end of the range, some of the Ss went off scale on the Variac. At the low end of the range, the settings of some Ss were limited by the fact that the light could not be seen at voltages below about 15 V. This restriction presumably accounts for the failure of the lowest points in Fig. 1 to follow the straight line (power function) drawn through the other points. If the same type of experiment were to be repeated with the same apparatus, it would perhaps prove advantageous to use a shorter range of sound pressure levels. In the present experiment there was more loudness range than there was usable brightness range.

Despite the experimental limitation on the brightness range, the matching procedure produced fair approximations to power functions for both children and adults. That, of course, is the result predicted by the psychophysical law (Stevens, 1953), and it is the relation that was verified for adults in the more extensive study by J. C. Stevens and Marks (1965). In that study the state of visual adaptation was controlled, a refinement that was not possible in the present experiment.

The congruence of the functions for children and adults suggests that, if the sensory power functions depend, not on the built-in features of the sensory systems, but on comparisons made among verifiable stimulus relations, the 5-year-olds in this experiment have demonstrated a most remarkable ability to grasp and remember the complex functional relations among different kinds of varying stimulus dimensions. It seems simpler and more plausible to suppose that children and adults behaved similarly in the cross-modality matching task because they both have the same kinds of sensory systems.

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NOTES

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