

# The Role of Insight in Perceptual Learning: Evidence from Illusory Contour Perception

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## Abstract

The distinction between gradual and abrupt improvement in performance is commonly made in behavioral studies of learning. The learning of perceptual and motor skills is often characterized by gradual, incremental improvement and is found not to generalize over stimulus manipulations such as change in retinal size or location. In contrast, marked improvement in performance can occur suddenly—a phenomenon that has been termed “insight.” Previously, insight has been studied in the context of problem solving and similar cognitive-level tasks. In this chapter, we use an illusory contours shape-discrimination task to present evidence that perceptual learning can exhibit characteristics of insight. Observers exhibited an abrupt, dramatic improvement in their performance, which resembled an incident of insight. At the same time, however, the improvement showed a degree of stimulus specificity that previously was thought to characterize incremental, gradual learning. This juxtaposition of abrupt and stimulus-specific improvement suggests that the dichotomy between the two forms of learning needs to be revised. This idea echoes Hebb (1949), who argued that the insight/incremental-learning dichotomy may be artificial and that the two forms of learning need to be addressed within a single theoretical framework. In terms of brain mechanisms, this means that all types of learning may involve interactions between low-level and high-level representations of the stimulus.

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## 13.1 Introduction

Although recent studies of perceptual learning have taught us much about its behavioral and physiological aspects, most have focused on gradual and incre-

mental improvement in performance. Much less is known about the mechanisms underlying another important form of plasticity—one that involves an abrupt improvement in performance known as “insight.” An animal is said to show insight if a period of poor performance with no clear trend of improvement is followed by a sudden and marked increase in performance. Insight has been most extensively studied in the domain of problem solving, dating as far back as the seminal work of Wolfgang Köhler (1925) with chimpanzees and other animals, and continuing today (Kaplan and Simon 1990; Sternberg and Davidson 1995). But in fields such as visual psychophysics and electrophysiology, where perceptual learning has been extensively studied, the phenomenon of insight has been largely overlooked. One possible reason for this may be a tacit assumption that the neural changes that underlie insight are fundamentally different from the plasticity that gives rise to the more gradual forms of perceptual learning. It has been suggested that the incremental improvement observed in the acquisition of perceptual skills involves synaptic modifications in early cortical areas (see, for example, Karni and Sagi 1993; Poggio, Fahle, and Edelman 1992; Ahissar and Hochstein 1997; see also Fiorentini and Berardi, chapter 9, and Zenger and Sagi, chapter 10, this volume). The implication that perceptual learning may be understood as part of a continuum of activity-dependent plastic changes, like those which have been so useful in explaining neuronal development (Hubel, Wiesel, and LeVay 1977; Katz and Shatz 1996; Miller, Keller, and Stryker 1989), is obviously appealing. On

the other hand, this point of view places the mechanisms underlying perceptual learning at a level quite separate from those that are traditionally associated with insight. The sudden improvements in performance observed in insight phenomena have been taken to indicate a cognitive event that occurs more centrally. Insight seems to be a process involving the whole animal, as in Köhler's apes (1925), who suddenly realize the potential relation of disparate elements in their visual field.

Nevertheless, the two forms of learning may be more related than is currently thought. Hebb (1949) suggested that the dichotomy between insight and rote learning may be artificial, and that the two forms of learning may share common mechanisms.<sup>1</sup> Hebb asked: "Is insight or hypothesis—or, in the broadest terms, intelligence—something distinct from the mechanism of association?" (p. 163). He observed that "learning is often discontinuous; error curves show sharp drops without warning, and the kind of error that is made on one day may be quite changed in the next" (p. 159). He concluded that "insight . . . continually affects the learning of the adult animal" (p. 163), and that "it is not wholly separate from rote learning" (p. 164). Are Hebb's assertions valid for the case of perceptual learning? Is there evidence that insightlike phenomena are part of the process of learning to perform a perceptual task? In this chapter, we will argue that the answer to these questions is yes. Although we are used to think of insight in the context of high-level cognitive tasks (such as problem solving), abrupt improvements in performance, resembling an occurrence of insight, can be observed in visual perception, as well. A classic example is the perception of hard-to-segment pictures, such as the one shown in figure 13.1a, where a dramatic transition to the "correct" interpretation may occur spontaneously or as a result of a cognitive or visual hint. (After looking at figure

13.1a, readers may look at the original gray-scale image, in figure 13.1b, as a visual hint, and then go back to figure 13.1a to experience the changed perceptual organization.) Using a task that involves a similar (but much-simplified) transition in perceptual organization, we will show that, under appropriate experimental conditions, it is possible to cause the "sharp drops" in error curves mentioned by Hebb to occur at a predictable time. The ability to gain experimental control over *when* the unique event of insight occurs addresses a long-standing problem that researchers have faced, and suggests that perceptual learning may be a particularly suitable paradigm to study the role of insight in learning.

We will also address the relation between stimulus specificity and insight in perceptual learning. As discussed in chapters 9 and 10 of this volume, it is often found in studies of perceptual learning that the improvement in performance does not generalize across stimulus attributes such as retinal size and location, or shape (Ramachandran and Braddick 1973; Fiorentini and Berardi 1980; Karni and Sagi 1991; cf. chapters 9–12). Indeed, these findings have played a major role in driving theories that place the site of plasticity in perceptual learning at early cortical areas (e.g., area V1; Fiorentini and Berardi 1980; Karni and Sagi 1991). At first glance, we might expect improvements from insight not to be susceptible to such superficial changes of circumstances and thus to generalize to stimuli that differ only in low-level visual properties. But in our experiments, the insightlike abrupt learning does not generalize to a new retinal size. This finding echoes reports from the literature on problem solving, that subjects' ability to generalize an insightful solution, that is, to transfer the solution to a novel context, depends on the extent of surface-level similarity between problems (Gick and Holyoak 1980; see also Ippolito and Tweney 1995 on the specificity of expert insights).



**Figure 13.1a**

Image obtained from gray-level original by blurring with a Gaussian filter, followed by two-toning (turning all the pixels above a threshold level to white, and those below, to black). In the resulting hard-to-segment image, the correct figural organization is not readily observed. Subjects may discover the embedded image spontaneously, or as a result of a verbal or visual hint. (The verbal hint is “ε μιοδ ιu ε ιιλ doup”; the visual hint—the original image—is shown in figure 13.1b.) The transition from perceiving this image as a set of random ink blots to seeing the figure embedded in it occurs abruptly, as an all-or-none event, resembling an occurrence of “insight.”

In this context, the stimulus specificity of abrupt learning calls for reevaluation of the way we think about insight and its role in perceptual learning, and about the source of stimulus specificity in learning phenomena in general.

### 13.2 Abrupt Learning Specific to Retinal Size

The task we used required subjects to discriminate between two possible shapes of an illusory surface that was globally defined by four inducers located at

the corners of a “Kanizsa square” (Kanizsa 1979). Rotating the inducers about their centers made the illusory shapes appear “thin” or “fat” (see figure 13.2). Performance on this task is measured by the magnitude of rotation angle of the inducers needed to yield reliable discrimination between the two possible shapes. Previous studies using this task concluded that perception of the curved illusory contours (ICs) significantly increases the accuracy of discrimination, compared to how well the task can be done based on discriminating the orientation of the local inducers (Ringach and Shapley 1996; Rubin, Nakayama, and Shapley 1996). Our results offer independent support for this interpretation. The initial performance of subjects was quite poor, characteristic of judgments based on the orientation of the local inducers; the abrupt improvement in performance found subsequently was often reported to occur together with a change in perceptual organization, as subjects began to perceive the illusory contours.

To allow for substantial room for improvement, the parameters of the stimuli were chosen so as to make the task quite demanding. The side of the global (illusory) surfaces was 15 cm, which led to retinal sizes of  $14.3^\circ$  and  $5.7^\circ$  visual angle in the two viewing distances used (60 cm and 150 cm, respectively). The *support ratio*, defined as the ratio between the luminance-defined part of the illusory-surface edge and the total edge length, was 0.25 (except where noted, see below). The stimuli were presented briefly, followed by a blank screen and a mask (see figure 13.2). To establish that they understood the task, subjects were given a practice session before collection of the experimental data; in the practice blocks the illusory shapes were highly visible due to the larger inducers’ size—the support ratio was 0.4 (the size of the global illusory surfaces was the same

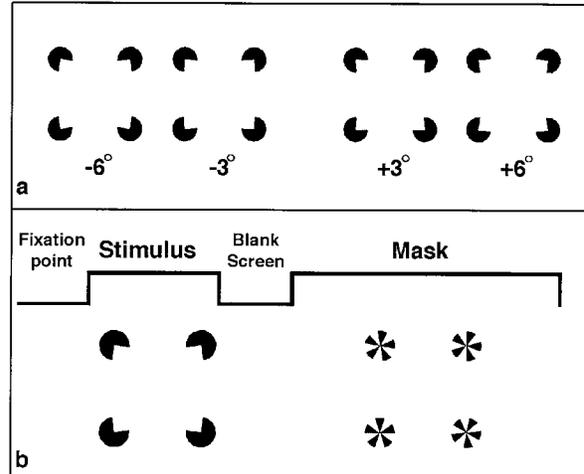


**Figure 13.1b**

Original gray-level image from which figure 13.1a was produced can be used as a “visual hint” to see the embedded figure.

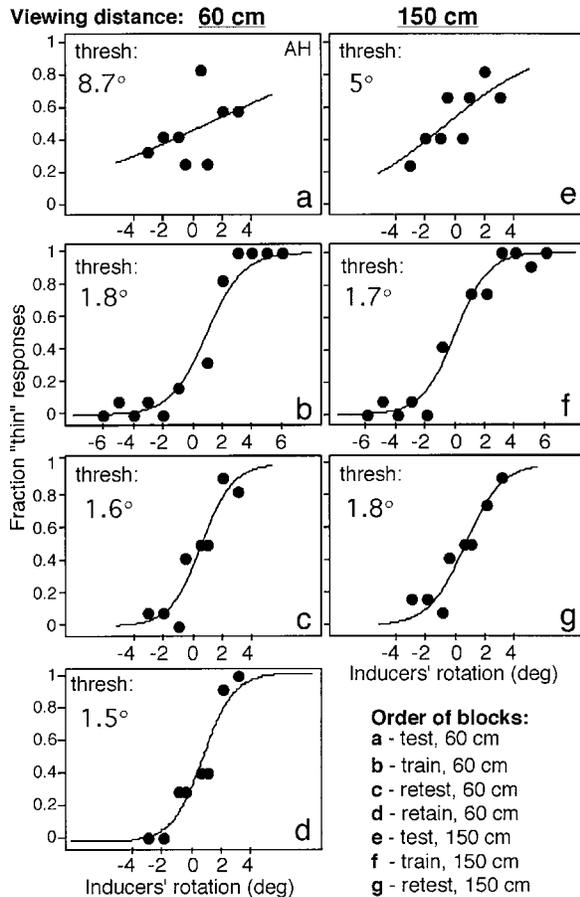
as in the experimental blocks). The practice session consisted of four examples of long-duration stimuli, followed by 20 presentations of brief, masked stimuli. Subjects were required to give at least 17 out of 20 correct responses in their first or second practice block in order to participate in the experiment (3 out of subjects 33 were rejected from the experiment due to failure on this criterion). Once they passed this criterion, they were given the experimental blocks, where the IC stimuli were less salient, because of the smaller inducers' size. Subjects were given feedback in the form of a computer beep after correct responses throughout the practice and all experimental blocks.

Figure 13.3 shows the performance of an individual observer (A. H.) in seven consecutive blocks. The probability that the subject judged a given stimulus (i.e., a given value of inducers' rotation) as “thin” was computed for the twelve repetitions of that



**Figure 13.2**

Shape discrimination task based on the perception of illusory contours. The inducers of a Kanizsa square were rotated about their centers by a variable degree, resulting in the perception of curved illusory surfaces of “fat” (left) or “thin” (right) shapes. Observers were required to choose between the two alternatives. (a) Direction and degree of inducer rotation determined the sign and amount of curvature of the illusory surfaces, respectively (our convention is to denote the direction of rotation that produced “fat” surfaces as negative). The range of curvatures used was varied from one experimental block to the other, thus allowing for control of the level of difficulty and the onset of the abrupt learning. (b) Each trial consisted of a brief stimulus presentation of either a “thin” or “fat” surface from the range of curvatures used in that block, followed by a blank screen and then a mask, which was designed to interfere with the perception of the inducers but not the global illusory surface. The stimulus was presented for 97 msec in the first experiment reported here, and for 97–194 msec in subsequent experiments (see text). The blank screen and the mask were presented for 69 msec and 250 msec, respectively.



**Figure 13.3** Performance of an individual subject (A. H.) in seven consecutive blocks of the “thin”/“fat” task. For each of the blocks, the fraction of times (out of 12 repetitions per stimulus value) that the subject judged the stimulus to be “thin” is plotted as a function of the inducers’ rotation angle. A sigmoid curve,  $[1 + \tanh(\beta(x - \alpha))]/2$ , was fit to the data, with the slope ( $\beta$ ) and bias ( $\alpha$ ) as free parameters. The threshold, defined as the inducers’ rotation angle needed to reach 82% correct discrimination, was estimated from the fitted curve. For each block, the threshold is shown at the top left corner. The blocks shown in panels a–d were performed at a viewing distance of 60 cm. (a)

stimulus within each block. The psychometric functions depict performance in each block in terms of the probability of responding “thin” to a stimulus as a function of that stimulus’s curvature. The data were fitted with a sigmoid function (see figure 13.3 caption) and thresholds were estimated from the fitted function. The first three experimental blocks were performed when the subject was seated at a viewing distance of 60 cm; each block took about 10 minutes; the whole session, including the practice and breaks, took about 45 minutes.

The first block (“test”; figure 13.3, panel a) consisted of stimuli where the inducers’ rotation angles were small (0.5–3°). Performance was poor (threshold: 8.7°). In the next block (“train”; panel b), stimuli with larger inducer rotation angles (4–6°) were added to the stimulus set. In addition, large-curvature stimuli of longer exposure duration (139 msec + 56 msec blank screen) were inter-

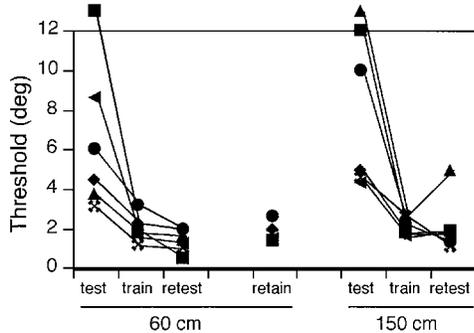
“Test” block: when the range of rotation of the inducing elements was 0.5–3°, performance was poor. (b) “Train” block: when high-curvature stimuli (4–6°; as well as longer-duration stimuli; see text) were added to the set, the subject’s performance improved markedly on the 2° and 3° stimuli, which were identical to those used in the “train” block. (c) “Retest” block: a repeat of the stimulus set used in the “test” block. After exposure to the “train” block, the subject was able to discriminate these stimuli reliably. (d) “Retain” block, run one week later: the subject still performed well on the low-curvature stimulus set, indicating that the learning was long-lasting. (e) The subject was moved to a viewing distance of 150 cm: performance in the “test” block, consisting of low-curvature stimuli, revealed that the learning exhibited in panels b–d was specific to the retinal size used. (f, g) Exposure to high-curvature stimuli again triggered marked improvement, and the subject’s final performance in the “retest” block (panel g) was similar to that in the 60 cm viewing condition.

mixed. As is evident from panel b, the observer's performance improved dramatically: the threshold in this block was  $1.8^\circ$  (the data from longer exposure duration stimuli were not included for the calculation of the threshold). That the subject performed well on the higher-curvature stimuli is to be expected because they are inherently easier to discriminate. But note that performance improved markedly also on the low-curvature stimuli: A. H. correctly discriminated in this block between "thin" and "fat" figures with curvature values of  $2^\circ$  and  $3^\circ$  in 92% and 96% of the trials, respectively, compared to only 58% and 63% on identical stimuli in the previous block. This dramatic improvement was not due to a lack of cognitive understanding of the task in the first block—A. H. got 20 out of 20 trials correct in the practice block. Would good performance on low-curvature stimuli always require the presentation of high-curvature stimuli in the same block? This was tested in the third block ("retest"; panel c), which consisted of a stimulus set identical to that of the first block. The good performance was maintained (threshold:  $1.6^\circ$ ), indicating that, compared to the poor performance exhibited in the "test" block, A. H. had undergone a rapid process of perceptual learning: he could now perform well on a set of stimuli that were too difficult for him before.

The remaining four experimental blocks were run a week later. The fourth block ("retain"; figure 13.3, panel d) was again a repeat of the low-curvature stimulus set. The good performance was maintained (threshold:  $1.5^\circ$ ), indicating that the learning obtained a week before was long-lasting. Immediately following the "retain" block, the subject was moved to a new viewing distance of 150 cm, and here we found that the long-lasting perceptual learning described above was specific to the trained retinal size. Because the size of the stimuli on the screen was

unchanged, the greater viewing distance meant that the retinal size of the stimuli became smaller: the side of the illusory surfaces was now  $5.7^\circ$  visual angle (inducers' size:  $1.4^\circ$ ), compared to  $14.3^\circ$  visual angle (inducers:  $3.6^\circ$ ) at the 60 cm viewing distance. The first block at this new viewing distance ("test"; panel e) consisted of low-curvature stimuli, like those in the "test" and "retest" blocks at the 60 cm viewing distance. Performance fell markedly compared to before (threshold:  $5^\circ$ ). Thus the learning observed in the 60 cm viewing distance did not generalize to the new retinal size. To ensure that good performance was in fact possible for this smaller retinal size, the subject was given a "train" block similar to that used at the 60 cm viewing distance, where high-curvature ( $4\text{--}6^\circ$ ) stimuli were mixed in with the low-curvature stimuli (panel f). This procedure again triggered a rapid improvement, leading to similar performance to that observed before (threshold:  $1.7^\circ$ ). The final block at the 150 cm viewing distance was again a repeat of the low-curvature stimulus set ("retest"; panel g), but this time performance was good (threshold:  $1.8^\circ$ ), indicating that the subject was able to learn the task at the new retinal size as well.

Figure 13.4 summarizes the results of six naive observers who were given the same sequence of blocks as A. H., in terms of threshold performance as a function of block type. All subjects showed sharp improvement in the transition from the "test" to the "train" blocks, and a lack of generalization of the learned performance to the new retinal size. As discussed earlier, the level of performance after the learning indicates that the subjects were basing their judgments on perceived illusory contours, whereas the poor level of performance in the "test" blocks is characteristic of a strategy based on making judgments based on the differences in the local inducers' orientation.



**Figure 13.4**

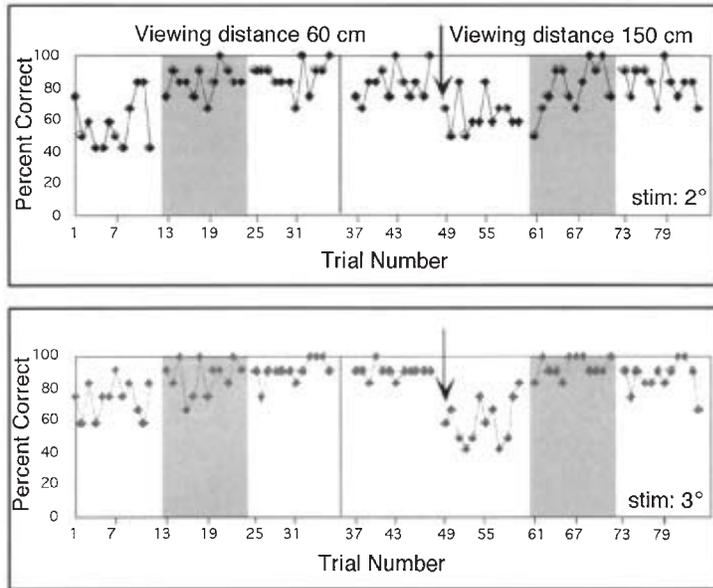
Results from six naive observers summarized in terms of threshold performance as a function of block type. The data for the first three experimental blocks were collected in one session, at a viewing distance of 60 cm. The initial performance (“test” block) varied greatly between observers, but all showed a marked improvement in the “train” block, and the good performance persisted in the “retest” block, which was a repeat of the stimulus set used in the first block. The data for the “retain” block, which was again run at 60 cm viewing distance, and for the three subsequent blocks, which were run at 150 cm viewing distance, were collected 1–7 days after the first session, to avoid fatigue of the naive subjects and to establish that the learning was long-lasting. (Results similar to those presented here were obtained from two experienced observers who performed all blocks on the same day.) The “retain” block was a repeat of the “retest” block stimulus set, and demonstrates that the learning is long-lasting; the poor performance in the “test” block at 150 cm demonstrates that the learning did not generalize to a new retinal size, but performance improved again after retraining.

### 13.3 The Time Course of Learning: A Trial-by-Trial Analysis of Performance

Thus far, we have seen that performance in the task can improve rapidly in the transition from the “test” to the “train” block. But in the data shown in figures 13.3 and 13.4, performance for each stimulus type is averaged across all twelve trials in the block. To

better examine the time course of the learning, we performed a trial-by-trial analysis of the performance of our subjects’ group. Data points in figure 13.5 represent the percentage correct of discriminations for the pair of  $\pm 2^\circ$  stimuli (upper panel) and the pair of  $\pm 3^\circ$  stimuli (lower panel) as a function of time (i.e., the serial order of presentation of the stimulus in the block, or trial number). Each point in figure 13.5 represents the mean performance in that trial, averaged over all six subjects. For both the  $\pm 2^\circ$  and the  $\pm 3^\circ$  stimuli, the group performance shows an abrupt jump at the transition from the “test” to the “train” block (trials 13–24, shaded area), when the low-curvature stimuli were embedded in a set of high-curvature and long-exposure stimuli. The mean performance on the  $\pm 2^\circ$  stimuli jumped from 58% in the “test” block to 84% in the “train” block (the numbers for the  $\pm 3^\circ$  stimuli are 74% and 88%, respectively, a smaller but yet significant effect). In both cases, no improvement is observed within the “test” block: linear regression accounts for less than 3% of the variance in the data and the regression slopes are very shallow. The trial-by-trial analysis again shows that the good performance was maintained in the “retest” block (trials 25–36), and in the “retain” block (trials 37–48), which was run on the second session, one to seven days later. After the subjects were moved to the 150 cm viewing distance, a sharp drop in performance was observed on the first, “test” block (trials 49–60), followed by a rapid improvement on the “train” (trials 61–72) and “retest” (trials 73–84) blocks.

The time course of improvement manifested in figure 13.5 is different from what is usually reported in perceptual learning studies—a gradual, even if sometimes fast (Karni and Sagi 1993; Poggio, Fahle, and Edelman 1992; Fahle, Edelman, and Poggio 1995) increase in performance (Ramachandran and



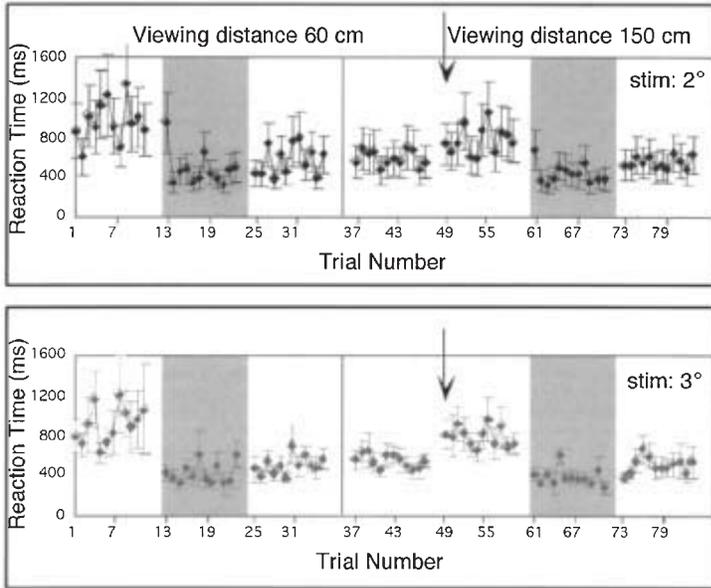
**Figure 13.5**

Trial-by-trial analysis of performance as a function of time. Percent correct discrimination for each successive pair of  $\pm 2^\circ$  (top) and  $\pm 3^\circ$  (bottom) curvature stimuli was separately tabulated, averaged over all six observers, and plotted as a function of time. Trials 1–12 were in the “test” block at the 60 cm viewing distance. Trials 13–24 (shaded zone) reflect the performance when identical stimuli were given in the “train” block, embedded in a set of higher-curvature and longer-duration stimuli. Trials 25–36 were in the “retest” block, which consisted of a stimulus set identical to that of the initial “test” block. The last four blocks, again of twelve trials each, were performed on a second session, between one and seven days later for different observers. The “retain” block (trials 37–48) was performed at the 60 cm viewing distance and the next three blocks were performed right after it, at the 150 cm viewing distance. Poor performance in the “test” block (trials 49–60) indicates that the learning did not transfer to the new viewing distance, although learning subsequently reoccurred in the “train” (trials 61–72) and “test” (trials 73–84) blocks for the new retinal size.

Braddick 1973; Ramachandran 1976; Fiorentini and Berardi 1980; Ball and Sekuler 1982; Karni and Sagi 1991; Ahissar and Hochstein 1993, 1997; cf. chapters 9, 11, 12). What is the relation between the abrupt, insightful learning we observed and the more gradual form of learning reported in other studies? We shall return to the implications of this distinction in section 13.5.

Subjects’ reaction times (RTs) also reflect a sudden, but stimulus-specific improvement. Figure 13.6

shows the trial-by-trial analysis of the RTs to the  $\pm 2^\circ$  (top panel) and  $\pm 3^\circ$  (bottom panel) stimuli. The pattern of performance parallels that found in the percentage correct data (figure 13.5), with a sharp drop in mean RTs at the transition between the “test” and “train” blocks at the 60 cm viewing distance, an increase in mean RTs as subjects were moved to the 150 cm viewing distance, and finally again a drop in mean RTs on the “train” block at the new viewing distance. In addition, a



**Figure 13.6**

Trial-by-trial analysis of reaction times (RTs). Mean RTs for each successive pair of  $\pm 2^\circ$  (top) and  $\pm 3^\circ$  (bottom) curvature stimuli are plotted as a function of time (average of six observers). At the 60 cm viewing distance, trials 1–12 were in the “test” block; trials 13–24 (shaded zone), in the “train” block, where a marked drop in the RTs is observed; trials 25–36, in the “retest” block; and trials 37–48, in the “retain” block. At the 150 cm viewing distance, trials 49–60 were in the “test” block, where mean RTs increased and percentage correct performance fell off, as also observed in figure 13.5; trials 61–72, in the “train” block, where facilitation is observed again; and trials 73–84, in the “retest” block.

slight increase in mean RTs can be observed in the “retest” blocks (trials 25–36 and 73–84), indicating that observers were aware that these were more difficult than the preceding ones (“train”), although this increase in difficulty is not manifested in the percentage correct performance (figure 13.5). Note that the subjects were not told that their reaction times were being recorded; the only emphasis in the instructions was on the correctness of responses. In other words, the sharp drops in the mean values and variability of the RTs occurred even though the subjects were not instructed to respond as fast as possible, and suggest that a facilitation in performing the task took place.

The trial-by-trial analysis reveals a course of improvement that follows closely Hebb’s behavioral criterion (1949, p. 160) for “insight”: “There is a period first of fruitless effort in one direction, or perhaps a series of solutions. Then suddenly there is a complete change in the direction of effort, and a cleancut solution of the task.” As mentioned earlier, the high thresholds in the “test” block are characteristic of performing the task based on the local inducers’ orientation, whereas the good performance later indicates judgments based on illusory contour perception. This finding suggests that the improved performance was indeed associated with a changed strategy, or “direction of effort,” as Hebb suggested.

The subjective reports of the observers are consistent with this idea. Several subjects reported that, in the first block, they did not see the global illusory shapes, and were basing their judgments on the local inducers; in the second block, they suddenly started seeing the global shapes (sometimes noting the well-known brightness effect associated with it; Kanizsa 1979; see also Petry and Meyer 1987). Thus both the subjective reports and the behavioral measures are consistent with a transition in subjects' strategy in performing the task, somehow triggered by the introduction of the "train" block. Interestingly, there was a notable difference between subjects who were practiced psychophysical observers (but were still naive about the purpose of our experiment), all of whom reported a transition in their strategy, compared with unpracticed subjects, who were much more likely to ascribe their improvement to their belief that the second block was "easier." That insightlike behavior can be triggered experimentally by appropriate "hints," even when subjects are unaware of the hints, has been known in the domain of problem solving for a long time (Mayer 1995).

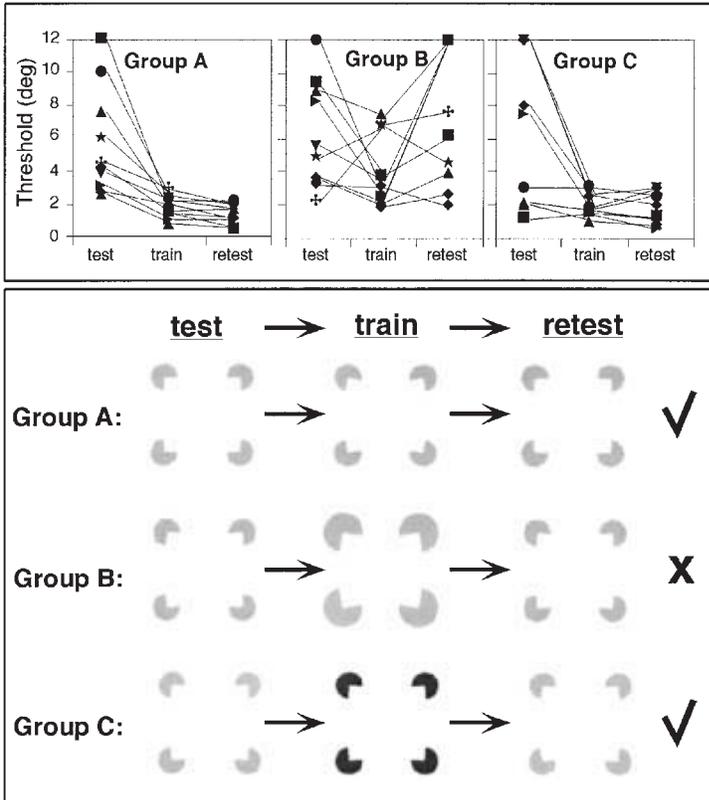
Our results suggest that insightful learning may not be limited to domains such as problem solving, but rather may play a role in perception as well. This view is further supported by our findings about the role of external feedback in learning. During our pilot studies, we ran different subjects with and without feedback, and found that, on average, subjects who did not receive external feedback about their correctness did not show as robust learning as those who did. Again, this finding was particularly true of subjects who were not practiced psychophysical observers; in contrast, two practiced (but naive) subjects showed an abrupt and long-lasting improvement in the absence of any external feedback. On the other hand, recall that the insightlike

improvement in performance was specific to the trained retinal size, and retraining was necessary at the new retinal size. Thus there seems to be an interaction between the low-level (exposure to specific stimuli) and high-level (strategy, knowledge about the level of correctness) aspects of the abrupt learning; we shall return to this point in section 13.5 (cf. also chapters 11, 20).

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### 13.4 Will Any "Easy" Stimulus Set Trigger Abrupt Learning?

We have seen that the abrupt learning did not generalize to a new retinal size, that is, the training procedure was effective only for the retinal size of the stimuli used in the "train" block. Next we examine further the extent to which the abrupt learning was sensitive to the specific attributes of the stimuli in the "train" block. First, we asked whether learning would take place when the large-curvature illusory surfaces had the same retinal size as before, but the inducing elements were of a different size. To test this, we ran a new group of ten subjects, which we designated "group B," on the first three experimental blocks of the "thin/fat" task (i.e., only the first session, at 60 cm viewing distance; the subjects received a practice block first, as before). The experiment performed by group B was identical to the first session in the experiment described before, except for the following change: the diameter of the inducers of the high-curvature stimuli ( $4-6^\circ$ ) was increased, leaving their centers at the same locations as before, so that the support ratio was 0.4. This change in diameter meant that the retinal size of the inducing elements was different from that used for the low-curvature stimuli, whereas the size of the *illusory* surfaces was the same for the two types of stimuli (see illustration in middle row of figure 13.7,



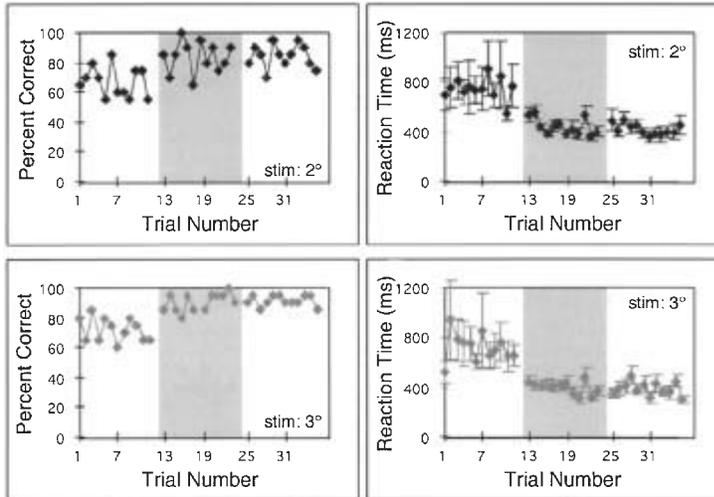
**Figure 13.7**

Specificity of the training stimuli. (*Bottom*) Schematic diagram of the different procedures used for the three experimental groups. Group A was given a “train” block with large-angle stimuli of the same inducer size as the small-angle (“test”) stimuli (and those in the first three blocks in figures 13.3–13.6). Group B was given a “train” block where the high-curvature stimuli were of larger-size inducers than the “test” stimuli. Group C was given a “train” block that contained long-duration low-curvature stimuli, and no high-curvature stimuli (the longer-duration stimuli are illustrated here schematically by higher contrast). (*Top*) Subjects in group A (*left*) and group C (*right*) show a dramatic improvement in their performance, which is maintained after the training stimuli are again removed (“retest”). Subjects in group B (*middle*) show large individual differences; many do not improve during the “train” block at all, and those who do improve during the training block do not retain the good performance once the large-angle stimuli are taken away (“retest” block). The thresholds for the “train” block were estimated based on the data from the 1–3° short-duration stimuli only, for all three experimental groups.

bottom panel). Note that this manipulation makes discriminating the shapes of the high-curvature stimuli of the “train” block even easier than before. Would exposure to these stimuli lead to robust learning? The results are shown in figure 13.7 (middle panel on top) in terms of threshold performance as a function of block type. For comparison, we include the results of ten subjects who participated in the first session of the experiment described in section 13.2, where the “test” and “train” stimuli had the same support ratio (group A, left panel on top). It is evident that, whereas all the subjects in group A improved in the “train” block and retained their learning in the “retest” block, the subjects of group B showed large individual differences in their performance. Moreover, the performance of even those subjects who improved during the “train” block fell back to its initial (“test”) level in the third, “retest” block. We conclude that the improvement in performance observed in group A, and the accompanying transition in the perceptual organization of the small-curvature (“test”) stimuli into illusory surfaces, can only be triggered by large-curvature IC stimuli with similar size inducers (i.e., with the same support ratio). One reason for this result may be that illusory contours of different support ratios are generated or represented by different neural substrates, even though the illusory surfaces themselves look perceptually similar (e.g., different neurons respond to the local occlusion cues, or L-junctions, as the support ratio is changed, because those junctions fall on different retinal locations). Alternatively, the lack of learning observed in group B may be related to cognitive factors: the mixture of “very easy” and “very hard” stimuli that are easily discriminable (due to the different support ratios) in the same block may have led to a differential treatment of the two sets of stimuli by the subjects. Further experiments will be

needed in order to distinguish between these two possibilities (or to show the involvement of both).

The next question we asked was whether the “train” block had to contain high-curvature stimuli, or whether learning could be induced with other, “easy” stimuli. This question addresses a possible interpretation of the abrupt learning observed in section 12.2, which is that the introduction of the high-curvature stimuli allowed the subjects to establish two distinct categories, or templates, for the “thin” and “fat” surfaces. According to that interpretation, the minute differences in curvature given in the first (“test”) block were not enough to establish two such distinct categories, and this led to the poor performance observed. Once subjects were able to form the categories, using the exaggerated examples given in the “train” block, they were able to classify the low-curvature stimuli correctly, too. This interpretation suggests the following prediction: significant improvement should not be observed when the “train” block is changed so that large-curvature stimuli are no longer given. This prediction, however, was not supported by the following experiment. A third group of subjects (group C) was given three consecutive experimental sessions, where the second (“train”) session consisted of only low-curvature ( $1-3^\circ$ ) stimuli. To facilitate performance in this block, two sets of long-duration low-curvature stimuli were added to the stimulus set: 153 msec (+69 msec blank screen) and 194 msec (+83 msec blank screen; the rest of the  $1-3^\circ$  stimuli had exposure durations of 97 msec + 69 msec blank screen, as in the “test” block). In other words, what made the additional stimuli in the “train” block easy this time was that they had, not higher curvature, but a much longer exposure duration. The results of group C are presented in figure 13.7 (right panel, top) in terms of threshold performance as a function of block type,



**Figure 13.8**

Trial-by-trial analysis of percentage correct (left-hand panels) and reaction time (right-hand panels) of group C, who received a “train” block that contained long-duration low-curvature stimuli, and no high-curvature stimuli (see figure 13.7, bottom panel, bottom row). Abrupt improvements, similar to those observed for group A (see figures 13.5 and 13.6), are seen at the transition (trial 13) from the “test” to the “train” block.

and show that long-exposure stimuli are sufficient to trigger learning. Figure 13.8 shows the trial-by-trial analysis of the percentage correct (panels on right) and reaction times (panels on left) performance, for the  $\pm 2^\circ$  (top panels) and  $\pm 3^\circ$  (bottom panels) short-duration stimuli. Abrupt improvements, similar to those observed before (see figures 13.5 and 13.6) are seen at the transition from the “test” to the “train” block. These results show that high-curvature stimuli are not necessary to trigger the learning. Therefore, the interpretation outlined above, which invoked the notion of a generation of two distinct categories for the learning to occur, must be rejected. Our results suggest instead that there may be several routes to facilitate learning (e.g., group A, group C), although not any set of “easy” stimuli is suitable (group B).

### 13.5 Discussion

Using a task of discriminating the shapes of global illusory surfaces, we were able to show that, under appropriate experimental conditions it is possible to induce a sudden and long-lasting improvement in performance. The overt measures of improvement—sharp drops in error rate and reaction times—were often accompanied by subjects’ reports of a change in their strategy in performing the task, suggesting that the learning we observed was similar to the phenomenon of insight in humans and other animals (Köhler 1925; Sternberg and Davidson 1995). At the same time, however, the abrupt improvement in performance shared one of the main characteristics of perceptual learning: it was stimulus specific. The

improvement did not generalize to a new retinal size, and retraining was necessary for the good performance to reoccur. The onset of the learning also showed great sensitivity to the spatiotemporal properties of the training stimuli, again demonstrating a strong perceptual component in the learning.

The paradigm presented here provides a unique situation in which these two properties of the improvement—abruptness and stimulus specificity—occur together. Usually, they tend to characterize quite different forms of learning. Stimulus specificity has been found mostly in cases where the learning was gradual and incremental—often requiring hundreds or even thousands of trials (Ramachandran and Braddick 1973; Ramachandran 1976; Fiorentini and Berardi 1980; Ball and Sekuler 1982; Karni and Sagi 1991; Ahissar and Hochstein 1993, 1997; Masson 1986; but see also Karni and Sagi 1993; Poggio, Fahle, and Edelman 1992). Insight, on the other hand, involves a sharp improvement by its very nature. Moreover, the name “insight” itself suggests that the subject has found some new “solution” to the problem at hand—a new understanding of how to perform the task or solve the problem. It implies that we should not expect the improved performance to be dependent on factors such as the context (e.g., in the case of problem solving) or the retinal size or location of the stimulus (in the case of a visual task). Research in problem solving, however, indicates the this expectation is not always met: in fact, subjects can show great susceptibility to the surface-level attributes of a problem they learned to solve, transferring the solution to another problem that shares these attributes, but failing to transfer it to a problem that has an identical deep structure but a different surface-level structure (Gick and Holyoak 1980). These findings echo those reported here, that an improvement which seems to involve an “insightful” solution can be stimulus specific.

The fact that abrupt (or insightful) and stimulus-specific improvements can happen within the same experimental paradigm suggests that there may be a connection between the mechanisms that underlie these two forms of learning, which were previously thought of as separate. One implication of this view is that perceptual learning should be thought of as *an active process*, where the subject’s continual effort to process the incoming sensory information in the most efficient and meaningful way is crucial for the improvement to take place. According to this view, the fact that abrupt improvement can be induced experimentally should be viewed as a manifestation of the underlying active process of exploration on the part of the subject, a process that is taking place continuously. Indeed, studies by Shiu and Pashler (1992) and Ahissar and Hochstein (1993; see also chapter 14, this volume) provide further evidence for this idea. In their experiments, an identical set of visual stimuli could be presented in the context of two different tasks. They found that the extensive exposure that gave rise to the improvement in the “main” (trained) task affected performance in the other (untrained) task very little. One exception to this finding, however, may be when the task is “preattentive,” in the sense of showing little or no performance loss as the attentional load is increased by enlarging the stimulus array (Treisman and Gelade 1980) or by introducing another, concurrent task (Braun and Sagi 1991). Ahissar and Hochstein (1993) found a significant amount of improvement in a popout task—a classical preattentive task—after subjects received extensive exposure to popout arrays in the context of a different task. Using a texture segregation task, Karni and Sagi (1993) distinguished two learning phases. The initial (“fast”) phase, takes place over several hundreds of training trials (in their study this initial phase was associated with a drop in thresholds of more than a factor of

two). Karni and Sagi (1993; see also Sagi and Tanne 1994) proposed that this phase involves top-down control and involves the establishments of connections that make the task automatic. The second, much slower phase of learning (which takes place over days and led to a further drop in thresholds of 30–40% in their study), is therefore hypothesized to be taking place in a passive, bottom-up way, requiring no active effort on the part of the observers.

The idea that incremental, stimulus-specific learning and abrupt, insightful improvements may be part of a common learning mechanism implies that it should be possible to show a continuous transition between these two forms of learning. There is evidence that such a continuum can indeed be observed. In the course of performing pilot experiments before those reported here, we ran a large group of subjects ( $n = 34$ ) on variations of the paradigm described in this chapter. Our purpose was to characterize the distribution of performance across our subject population, in order to optimize stimulus conditions for abrupt learning. By changing the exposure duration of all stimuli, we varied the overall level of difficulty of the task while at the same time maintaining the “test-train-retest” structure reported here (low curvature in the “test” blocks; mixed high- and low curvature in the “train” blocks). We found that, for shorter exposure durations than those reported here (i.e., when the task was more difficult), subjects often did not show an abrupt improvement at the transition from the “test” to the “train” block, but instead showed a slower, more gradual improvement (and sometimes did not improve at all within the session). These results also shed light on the issue of why traces of abrupt or insightful improvements were not reported previously in perceptual learning studies. To allow for a substantial amount of improvement, researchers used parameter regimes that made their tasks extremely difficult, and thus also made gradual,

incremental improvements more likely than large, sudden ones. This observation was made already by Hebb (1949, p. 160), who noted that in order to induce insight, one needs “tasks . . . of just the right degree of difficulty . . . [the task] must neither be so easy so that the animal solves the problem at once, thus not allowing [experimenters] to analyze the solution; nor so hard that the animal fails to solve it except by rote learning in a long series of trials.” Thus, while previous perceptual learning studies were not intended to optimize conditions for insightlike improvements to occur, it may well be the case that an appropriate change in the experimental procedure could promote such abrupt learning in other tasks as well (e.g., by using the method of constant stimuli to give a set of difficult stimuli followed by the same stimuli mixed in with easier ones, as we have done here). This in turn suggests that, by appropriate choice of the stimulus parameters and experimental procedure, perceptual learning may be used as a model for studying insight.

The resemblance between insight in problem solving and in perception has recently also been noted by researchers writing about the psychology of insight. Schooler, Fallshore, and Fiore (1995) found a strong correlation between insight in problem solving and the capability to find the shapes of objects in blurred pictures. Gruber (1995) specifically drew attention to similarities in the process of integration of fragmented images such as illusory contour stimuli and the integrative processes of insight in problem solving.

Another issue raised by the results presented in this chapter is the interpretation of stimulus specificity. The lack of generalization of perceptual learning to new stimulus parameters has been previously taken to imply that the learning occurred in early, retinotopically organized visual cortical areas, which are known to encode position, local orientation, and

similar attributes at the level of individual cells (Ramachandran and Braddick 1973; Fiorentini and Berardi 1980; Karni and Sagi 1991; Poggio, Fahle, and Edelman 1992; Weiss, Edelman, and Fahle 1993; Fahle 1997; Ahissar and Hochstein 1997; see also chapters 9–11, this volume). Placing the site of plasticity at an early visual cortical site was consistent with two notable characteristics of the tasks and the learning course. First, the tasks were of a local nature, involving interactions between image points  $1^\circ$  apart or less (Ramachandran and Braddick 1973; Karni and Sagi 1991; Poggio, Fahle, and Edelman 1992; Fahle 1997; Ahissar and Hochstein 1997). Second, the improvement was incremental, often taking place over hundreds or even thousands of trials (Ramachandran and Braddick 1973; Fiorentini and Berardi 1980; Karni and Sagi 1991; Fahle 1997; Ahissar and Hochstein 1997). Even where fast learning phases were observed (Poggio, Fahle, and Edelman 1992; Karni and Sagi 1993), performance showed a steep, but gradual improvement, over several dozens of trials. In contrast, in the experiments reported here, there were large retinal distances between the inducers (more than  $10^\circ$  visual angle at the 60 cm viewing distance), which means that the relevant information was stored in widely separated neurons in early visual cortical areas. This in itself does not preclude models that assume that the visual *processing* required to perceive the illusory contours takes place in those early, small receptive field areas because information can propagate in a few iterations across several relays of lateral connections (Gilbert and Wiesel 1983; Gilbert et al. 1996; Lund 1988; Malach et al. 1993; for a model that makes use of such lateral connections to detect global shapes, see also Sha'shua and Ullman 1988). But here is where the abrupt nature of the learning we observed comes into play. For a model based on lateral connections to exhibit the kind of sharp im-

provement we observed, it would require the simultaneous modification of synaptic efficacies between multiple (neighboring) cells. The existence of neural mechanisms that could support such a “cooperative” form of synaptic plasticity is not presently known. Thus the abruptness of the learning, combined with the global nature of the task make it unlikely that a model based exclusively on quick synaptic modifications of local connectivity in early cortical areas, such as has been suggested previously for other tasks (Poggio, Fahle, and Edelman 1992), could work for the phenomenon presented here. The fact that the abrupt learning we observed was specific to retinal size indicates, however, that the site of plasticity cannot be limited to higher visual areas that encode shapes in a size-invariant way, either. It is therefore difficult to conceive of the learning as occurring at a single site. Instead, the improvement we observed is more consistent with changes in processes that involve interactions between multiple levels of representation of the stimuli, where activity in early visual areas is affected by stimulus-driven processing as well as top-down control (Edelman 1987; Grossberg 1987; Ullman 1995; Dayan et al. 1995; cf. chapters 18, 20).

To conclude, we have shown evidence that insightlike improvements in performance can take place in perceptual learning, and that the improvement may show stimulus specificity similar to that described before for more incremental, gradual learning. Our results suggest that the distinction between insightful and gradual, incremental learning may need to be revised. Rather than postulating two distinct mechanisms for the two forms of learning, our findings may be better understood within a single framework. This view was put forward already by Hebb (1949), who wrote that “insight . . . continually affects the learning of the adult animal” (p. 163), and that “it is not wholly separate from rote

learning” (p. 164). Hebb proposed a unitary mechanism, based on the associations of co-occurring internal states, within which to understand all learning phenomena. However, he emphasized that the sequence of internal states is not merely determined by external events, but is rather an active process in which the animal is attempting continually to discover structure and meaning in the incoming information. This is a very different view from the incremental and unsupervised form of learning with which Hebb is usually associated today (see, e.g., Rumelhart et al. 1986; Brown et al. 1990). Reading his seminal book fifty years later, it is striking to see how this neuroscientist was in fact acutely aware of the role of insight in learning—especially because he later came to be identified with the idea of “associative learning,” which is today often equated with a passive, stimulus-driven and unsupervised form of synaptic plasticity. Our findings, as well as other evidence recently reported (Shiu and Pashler 1992; Ahissar and Hochstein 1993, 1997), vindicate Hebb’s original ideas and call for a more integrative approach to studying the organization of learning.

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### **Note**

1. *Rote learning* was the term used by Hebb to describe the gradual, incremental form of learning being studied in animals, primarily rats and pigeons, and modeled by the learning theorists of those days as a continuous process. The “mechanisms of association” Hebb mentions later refer to the central idea behind most theories of his time, that learning takes place as a result of the incremental strengthening of stimulus-response relations that gives rise to a desirable outcome (reward). Hebb himself, of course, is widely known for his contributions to learning theory; importantly for the present context, Hebb is probably best known today for his observation that learning via such a “mechanism of association” can occur in the absence of explicit supervision (reward or feedback), merely by the strengthening of pathways between co-occurring neural events.