confusions made by the two groups of readers, an assessment could be made of whether they differed in the kind or quality of information perceived. Across all sets of figures and delay intervals, normal and poor readers showed similar confusion error patterns. Both groups tended to choose an incorrect form that was visually confusable with the correct form.

Taken together, the results of this study showed that poor readers were not deficient in the quantity or quality of information they initially perceived or in the trace duration of that information in a raw perceptual form (VIS). Poor readers did show a striking deficit during the 300- to 2000-msec interval, which argues that reading disability involves some problem in the processing of information in stages following initial perception, perhaps in encoding, organizational, or retrieval skills. Also, reading disability is not limited to verbal materials since poor readers performed equally poorly compared with normal readers on the geometric and abstract forms. The real difficulty may involve a more abstract ability which underlies processing of both labelable and unlabelable forms. The conclusions drawn from this study must at present be restricted to older children since beginning readers were not included. Further research is needed to assess the generality across age of the processing deficit discovered here. Nevertheless, the fact that poor readers were found to be deficient in a form of processing that is not primarily verbal is important especially given a recent tendency to tie reading problems in older children to verbal and linguistic processes (*4*). The development of techniques that can tease apart component processes acting on information represents an important step toward clarifying the complex nature of reading disability.

FREDERICK J. MORRISON
BRUNO GIORDANI, JILL NAGY
Department of Psychology,
Dartmouth College,
Hanover, New Hampshire 03755

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6. Additional significant results included superior performance on the geometric forms over the letters and abstract forms [$F(2, 32) = 55.2$, $P < .0001$]; decrease in performance across delay intervals in the perceptual phase [$F(4, 80) = 60.2$, $P < .0001$); and an interaction between delay interval and type of figure, namely performance on the abstract forms and letters decreased more sharply in the 0- to 300-msec interval than did performance on the geometric forms [$F(10, 160) = 3.47$, $P < .0004$].
7. The output of this analysis provided a spatial configuration of items representing their judged similarity such that distance was monotonically and negatively related to similarity. A measure of the number of dimensions critical to task performance was obtained in the form of work level. This indicated the degree of difficulty incurred in accounting for data constraints within the respective number of specified dimensions, work level being inversely related to goodness of fit. Performance for both reading groups exhibited the best fit in a two-dimensional space with the work level for normal and poor readers being very similar: for example, 17.9 and 16.0, respectively, for the normal and poor readers on the abstract forms during the perceptual phase.
8. We thank J. C. Baird for valuable assistance.

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Homeostasis During Hypoglycemia: Central Control of Adrenal Secretion and Peripheral Control of Feeding

Abstract. *Intravenous infusions of mannose or β-hydroxybutyrate, metabolic fuels which can be oxidized by brain, abolished adrenal discharge of epinephrine in rats during insulin-induced hypoglycemia, whereas infusion of fructose, a sugar which does not cross the blood-brain barrier, did not. In contrast, increased feeding behavior during hypoglycemia was prevented both by the sugars and by β-hydroxybutyrate. Thus, while the sympathetic response during marked hypoglycemia may have been initiated by alterations in cerebral metabolism, the feeding response evidently was not, and a decrease in the utilization of glucose per se does not appear to be the critical stimulus in either case.*

Compensatory responses help to maintain caloric homeostasis during insulin-induced hypoglycemia. For example, the discharge of epinephrine from the adrenal glands (*1, 2*) promotes the mobilization of internal fuel reserves, while increased feeding behavior (*3*) provides a fresh supply of nutrients from extracorporeal sources. It has long been assumed that both of these reactions are triggered by central glucoreceptor cells, in response to the decreased supply of glucose that reaches the brain (*2, 4*). Recently, however, Flatt *et al.* (*5*) have shown that intravenous infusion of ketone bodies (β-hydroxybutyrate and acetoacetate), metabolic fuels which can be oxidized by brain (*6*), abolishes the increased adrenal medullary secretions of anesthetized dogs during insulin-induced hypoglycemia. We have extended those findings to conscious rats, and demonstrate that intravenous infusions of mannose also lower circulating catecholamine levels despite continued hypoglycemia, whereas infusions of fructose, a carbohydrate which is not readily utilized by rat brain (*7*), do not. Furthermore, in contrast with their differential success in affecting adrenal medullary secretion, we have found that each of these metabolic fuels suppressed the feeding response to exogenous insulin.

Male albino rats of the Sprague-Dawley strain (Zivic-Miller), weighing 300 to 350 g, were housed in individual wire-mesh cages and allowed free access to Purina Chow pellets and tap water, both in their home cages and during testing, except as noted. Forty-five rats were fitted with intracardiac catheters (*8*). Beginning 3 days later, when food and water intakes had returned to normal, the rats were placed in cylindrical testing chambers (42 cm high, 28 cm in diameter). Several hours were allowed for adaptation to these surroundings. At about noon, rats were given a single injection of regular insulin (3 units per kilogram of body weight) through their catheters to produce hypoglycemia. They were then connected by means of a watertight swivel and polyethylene tubing to an infusion pump and immediately began to receive either ketone bodies (1.2*M* sodium DL-β-hydroxybutyrate in 0.15*M* NaCl, at the rate of 3 ml/hour), sugar (1.2*M* solutions of glucose, fructose, or mannose, in water, at 2 ml/hour), or control NaCl solutions (0.15*M*, 0.75*M*, or 1.2*M*). Supplemental injections (2 ml/kg) of the various infusates were given by way of the catheters 10, 30, and 60 minutes later. Food and water intakes were measured every 30 minutes for 2 hours. Individual rats were usually tested with two or three different infusates, once every few days, until six to ten animals had been tested with each solution.

The effects of the various infusions on insulin-induced feeding are summarized in Table 1. Rats infused with 0.15*M* NaCl solution usually began to eat within 20 to 30 minutes after insulin treatment and continued to feed periodically throughout the 2-hour test (Table 1). Infusions of β-hydroxybutyrate, glucose, mannose, or fructose virtually abolished feeding af-

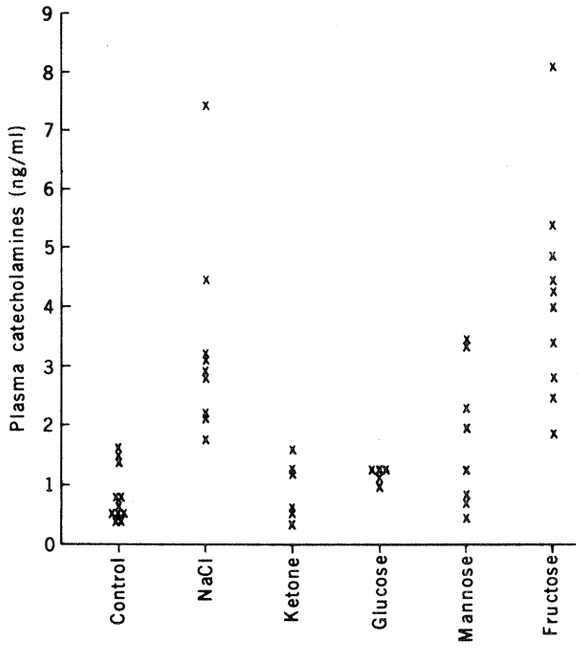

Fig. 1. Plasma catecholamines of rats given insulin (3 unit/kg, intravenously) and then infused with either 0.15*M* NaCl, 1.2*M* β-hydroxybutyrate (3 ml/hour), or 1.2*M* solutions of glucose, mannose, or fructose (2 ml/hour). Supplemental injections (2 ml/kg, intravenously) of the various infusates were given 10 and 30 minutes after the insulin was administered. Values are from individual animals 60 minutes after insulin treatment. Values from control animals given 0.15*M* NaCl instead of insulin are presented for purposes of comparison. Insulin treatment (plus saline infusion) increased plasma catecholamines significantly ($P < .01$), whereas infusions of β-hydroxybutyrate, glucose, or mannose significantly reduced that effect ($P < .02$, .02, and .05).

ter insulin (*9*), whereas control infusions of 0.75*M* or 1.2*M* NaCl solution had less effect (*10*). Despite the suppression of food intakes, the rats did not appear stressed or otherwise upset during the infusions.

To examine the effects of our treatments on the adrenal response during hypoglycemia, we injected rats with insulin and then infused them, as before, with β-hydroxybutyrate, glucose, mannose, fructose, or NaCl solutions. Groups of control rats received isotonic saline instead of insulin, followed by a continuous infusion of 0.15*M* NaCl or 1.2*M* fructose solutions. Supplemental injections (2 ml/kg) were given 10 and 30 minutes after insulin or control injections. Access to water, but not food, was allowed. After 1 hour, the rats were killed by decapitation and blood was collected from the neck into chilled heparinized tubes. A portion of whole blood was taken for later determinations of glucose (*11*), while plasma samples obtained by subsequent centrifugation were analyzed for catecholamines (*12*).

As expected, insulin (3 unit/kg) infused intravenously rapidly produced a substantial reduction in blood glucose concentration and an increase in plasma catecholamines in control rats ($r = -.78$ after 1 hour; $P < .001$), whereas neither effect was seen when the animals were infused with glucose (Fig. 1 and Table 2). Plasma catecholamines also were found to be within the control range in insulin-treated rats that were infused with β-hydroxybutyrate as well as in many animals that were given mannose, despite persistent hypoglycemia. Only in insulin-treated rats receiving fructose did circulating catecholamines remain elevated. This effect appears to be the result of the marked hypoglycemia, since control animals that were given fructose but not insulin showed no adrenal hypersecretion of catecholamines (range, 0.58 to 1.19 ng/ml; $N = 5$).

The adrenal discharge during hypoglycemia is believed to be triggered by receptor neurons in the brain that are activated by a decrease in the cellular glucose supply (*2*, *13*). However, the abolition of catecholamine secretion in insulin-treated rats by infusion of β-hydroxybutyrate or mannose may be attributed to the brain's capacity to utilize these alternative fuels when the supply of glucose is inadequate (*5*, *14*). These findings suggest that adrenal catecholamine secretion during hypoglycemia does not result from a decreased utilization of glucose per se, but rather from a decline in the availability to the brain of all utilizable fuels. In this regard, the failure of fructose infusions to block the adrenal discharge is consistent with previous reports that this sugar does not cross the blood-brain barrier in rats (*7*) and does not suppress the compensatory increase in hepatic glucose production that occurs during insulin-induced hypoglycemia (*15*).

While infusions of fructose did not affect the sympathetic response during hypoglycemia, they did eliminate the feeding response to insulin treatment. These results indicate that the signal for feeding behavior can have a peripheral origin. The liver has been implicated in the stimulation of hunger (*16*); however, because it is the only organ that cannot oxidize ketone bodies (*17*), the ability of β-hydroxybutyrate to attenuate feeding may indicate that the stimulus for hunger does not arise in the liver but in some other peripheral site. Alternatively, the induction of feeding may result from some change in hepatic metabolism that is stimulated by central chemoreceptors (*18*). Regardless, it seems evident that the sympathetic response during marked

Infusate	Food intake (g)
0.15*M* NaCl (10)	2.15 ± 0.28*
0.75*M* NaCl (9)	1.90 ± 0.25*
1.2*M* NaCl (10)	1.19 ± 0.43*
1.2*M* β-hydroxybutyrate (6)	0.73 ± 0.24
1.2*M* glucose (8)	0.27 ± 0.19
1.2*M* mannose (10)	0.20 ± 0.13
1.2*M* fructose (9)	0.38 ± 0.14

*$P < .001$.

Table 1. Food intake during 2-hour test. All rats were given insulin (3 unit/kg, intravenously) and then infused (2 or 3 ml/hour, intravenously) with various solutions. Supplemental injections (2 ml/kg) of the various infusates were given 10, 30, and 60 minutes later. Data are presented as mean food intake ± estimated standard error of the mean. Numbers of rats are indicated in parentheses. Statistical comparisons for each group were made with their intakes when they were given 0.15*M* NaCl instead of insulin (0.37 ± 0.23 g, for all rats tested).

Infusate	Blood glucose (mg/100 ml)
0.15*M* NaCl (9)	47.3 ± 4.2*
1.2*M* β-hydroxybutyrate (6)	33.1 ± 1.1*
1.2*M* glucose (5)	96.0 ± 10.6
1.2*M* mannose (8)	34.3 ± 5.2*
1.2*M* fructose (10)	52.7 ± 1.6*

*$P < .001$.

Table 2. Blood glucose values of rats given insulin (3 unit/kg, intravenously) and then infused (2 or 3 ml/hour, intravenously) with various solutions. Supplemental injections (2 ml/kg) of the various infusates were given 10 and 30 minutes later. Blood samples were obtained 60 minutes after insulin treatment. Food was not allowed during this interval. Data are presented as mean blood glucose ± estimated standard error of the mean. Numbers of rats are indicated in parentheses. Additional animals, treated identically but killed 30 or 120 minutes after insulin administration, showed similar values ($N = 2$ or 3 in each group). Statistical comparisons for each group were made with blood glucose levels in control rats not given insulin (108.0 ± 3.5 mg/100 ml, $N = 11$).

hypoglycemia is initiated by alterations in cerebral metabolism, whereas the feeding response is not, and a decrease in the utilization of glucose per se does not appear to be the critical stimulus in either case.

EDWARD M. STRICKER
NEIL ROWLAND
CHARLES F. SALLER
Psychobiology Program, Departments of Psychology and *Life Sciences, University of Pittsburgh, Pennsylvania*
MARK I. FRIEDMAN
Department of Psychology, University of Massachusetts, Amherst 01002

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9. Two grams of Purina Chow pellets yield 7.2 kcal. For rats weighing 333 g, the estimated caloric loads were approximately 6.6 kcal when β-hydroxybutyrate was infused (of the racemic mixture administered, only the D-isomer can be metabolized) and 5.2 kcal when the sugars were given.
10. Hypertonic NaCl is known to decrease food intake in hungry rats, presumably because of increased thirst [J. S. Schwartzbaum and H. P. Ward, *J. Comp. Physiol. Psychol.* **51**, 555 (1958); T. H. Yin, C. L. Hamilton, J. R. Brobeck, *Am. J. Physiol.* **218**, 1054 (1970)]. In our experiments, rats infused with 1.2*M* NaCl solution drank 18.8 ± 2.2 ml (mean ± standard error of the mean), significantly more than that consumed by rats infused with 0.15*M* NaCl (2.3 ± 0.6 ml; $P < .001$). Water intakes of rats infused with β-hydroxybutyrate or the sugars ranged from 0 to 5.9 ml and were not significantly different than those of rats receiving 0.15*M* NaCl.
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18. Consistent with this interpretation are findings that adrenal demedullation, which retards the increase in hepatic glucose production (*1*), attenuates the feeding induced by insulin [D. A. Booth, *Physiol. Behav.* **8**, 1069 (1972)]. Thus, the effectiveness of β-hydroxybutyrate, glucose, and mannose in our experiments may result from their demonstrated capacity to suppress the sympatheticoadrenal response (Fig. 1) (*15*), whereas the effects of fructose may instead result from a direct influence on hepatic metabolism which could not be reversed by this level of sympathetic activation. In this regard, we have recently found that intravenous injection of 4.4 units of insulin per kilogram, which lowers blood glucose to 30 to 40 mg/100 ml, stimulates larger increases in plasma catecholamines than are reported here, and elicits feeding in rats that could be totally suppressed by glucose or mannose but not by equimolar fructose solutions (N. E. Rowland and E. M. Stricker, in preparation).
19. We thank J. Yen for her technical assistance. Supported by NIMH grant MH-25140 (to E.M.S.).

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Bile, Prolactin, and the Maternal Pheromone

Abstract. *When bile from females that had been lactating for 21 days was injected into the cecum of male rats it induced release of a maternal pheromone. Males injected with bile drawn from females in which prolactin had been inhibited, or from females that had been lactating for only 5 days, did not emit the pheromone. These data suggest a sex difference in the way prolactin alters the composition of bile so that the female can emit the maternal pheromone while the male normally cannot.*

The maternally behaving lactating rat emits a pheromone that strongly attracts young (*1*). This pheromone, contained in the female's feces, is first released about 16 days after the start of lactation, corresponding to the age at which the young first become responsive to the pheromone. At about 27 days, pheromonal release ceases, which, in turn, coincides with the age at which the young cease to be attracted to the pheromone (*1*).

Under certain conditions, nulliparous females and adult males behave maternally. That is, they come to build a nest, lick, retrieve, and even crouch in a nursing posture when housed continuously with young—a procedure known as concaveation (*2*). Leidahl and Moltz (*3*) studied such concaveated animals to determine whether they also emit the pheromone. Briefly, the procedure was to provide each animal with a litter of foster pups approximately 24 hours old. These foster pups were allowed to remain in the cage until the following day, at which time a new litter of the same age was substituted. Replacing one 24-hour-old litter with another continued until the day a given animal started to behave maternally. Thereafter it was proffered fresh litters that advanced commensurately in age, so that on day 2 of maternal behavior it was caring for young 2 days old, on day 3 for young 3 days old, and so on.

The concaveated females began to emit the pheromone when their foster young reached 16 days of age, a time coincident with the onset of emission in the lactating female. We repeatedly tested the concaveated males, but in contrast to the concaveated females, they did not emit the pheromone. The question arises as to why the male, when behaving maternally in the same manner as the female, fails to emit the pheromone.

Knowing that high titers of prolactin are essential for pheromonal emission (*4*), we thought that perhaps the failure of the male to release the maternal pheromone was due to a failure to synthesize such high titers. Therefore, we took both intact and castrated males and injected them daily with prolactin [either 25 or 50 international units (I.U.)], starting on the first day that they began to behave maternally. The injections continued for a full 24 days, during which time they were tested repeatedly for the pheromone, according to the procedure previously described by Leon and Moltz (*1*). Not a single male showed evidence of the pheromone (*5*).

We then thought that perhaps the failure of these males to release the pheromone was due to a lack of estrogen. Accordingly, we undertook daily injections of both estradiol benzoate (5 μg) and prolactin, beginning, once again, on the first day of maternal behavior. Again, not a single male gave evidence of the pheromone (*6*). After this we gave up the idea of a simple endocrine insufficiency and sought instead to explain the failure of pheromonal emission by reference to events within the liver. What led us to focus on the liver can be described briefly as follows.

We knew from the work of Leon (*1*) that the pheromone is not the product of some anal gland but instead is synthesized within the cecum. We knew also from the work of Posner and his colleagues (*7*) and from that of Costlow *et al.* (*8*) that prolactin induces its own hepatic receptors and that the male characteristically shows a lower level of such