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Human Newborns Differentiate Differing Concentrations of Sucrose and Glucose

Abstract. *One- to three-day-old infants who sucked to obtain flavored water revealed a precisely graded tongue movement which was sensitive to the gustatory properties of the flavored water. Stronger concentrations of sucrose and glucose elicited movements of greater amplitude than did weaker concentrations; sucrose was effective at lower concentrations than was glucose. These results correspond well with the relative sweetness adults attribute to these solutions in psychophysical studies.*

We have found that newborn human infants respond differentially to two concentrations of two sugars precisely as human adults do.

The traditional ascription of incompetence to the newly born (*1*) has met with some jolts in recent years. The newborn learns (*2*), he sees (*3*), he hears (*4*), and, after a while, he divides up the world of speech (*5*), color (*6*), and space (*7*) into the categories familiar to us all. We looked at the human newborn's responses to tasteful substances primarily because of our interest in the transformation of reflex into representation (*8*). Along the way, we found out that infants, in the first days after birth, are able to indicate with fair precision their differentiation among various sweet solutions.

We tested 75 healthy full-term infants with a variety of gustatory stimuli in a broad investigation of the effectiveness of the pressure-transducing nipple described below. The data reported here are from those ten infants who received at least one other sugar concentration besides the standard glucose given to all infants. All infants tested were between 1 and 3 days of age.

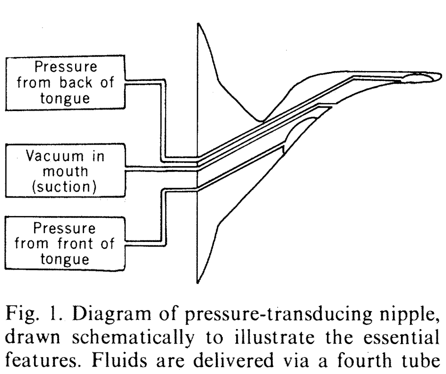

Fig. 1. Diagram of pressure-transducing nipple, drawn schematically to illustrate the essential features. Fluids are delivered via a fourth tube parallel to (behind, in this drawing) that shown for measuring vacuum in the mouth.

The recording nipple depicted schematically in Fig. 1 was constructed of medical grade Silastic rubber, and was designed to record independently the pressures exerted by the front and back of the infant's tongue, as well as the negative pressure created in the infant's mouth during sucking. The rationale for these several dependent variables is described elsewhere (*8*) in a theoretical discussion of the relative contribution to palatability of ingestive and rejective reflexes from the front and back portions of the mammalian tongue. Each channel of the recording nipple was connected to a Statham P23A pressure transducer, the output of which was amplified and recorded with a Grass model 7 polygraph. Sterile solutions were delivered to the infant's mouth through a fourth tube in the nipple parallel to that illustrated for measuring the vacuum in the infant's mouth. This tube connected the oral cavity directly to the fluid reservoir, which was kept at the level of the infant's mouth, so that negative pressure in the mouth directly delivered fluid to the mouth.

All infants were from a nursery in Yale–New Haven Hospital in which feedings were not scheduled by the clock; most were tested 3 to 5 hours after their previous feeding. The experimenter entered the nursery, where a nurse checked the infant for soiled diapers; the experimenter then carried the re-diapered infant to the experimental room in the newborn special care unit. The seated experimenter cradled the infant in his left arm and offered the nipple with his right hand. A second experimenter managed the polygraph and filled the sterile glass reservoir with 2 ml of the solution to be tasted. A "trial" lasted until the 2 ml were consumed or until the infant did not suck at all for 2 minutes. All infants offered sugar solutions under the paradigm described here rapidly consumed the 2 ml offered of each concentration. Five percent (0.277*M*) glucose was offered first to all babies, to provide a standard of response amplitude to which other solutions could be compared. The three other sugar concentrations we employed were 10 percent (0.555*M*) glucose, 2 percent (0.058*M*) sucrose, and 4 percent (0.117*M*) sucrose. Infants generally received three solutions other than the standard, but in some cases, reported elsewhere (*9*), these included mild solutions of sodium chloride or quinine hydrochloride, rather than all of the sugar solutions (*10*). Other infants, observed for their reactions to different versions of the recording nipple, received only the standard.

The results of major interest are summarized in Fig. 2. The anterior tongue pressure score is derived by taking the mean amplitude of the strongest ten sucks to a given concentration, and dividing that by the mean amplitude of the strongest ten sucks to the standard glucose concentration for that infant. Standard errors are in-

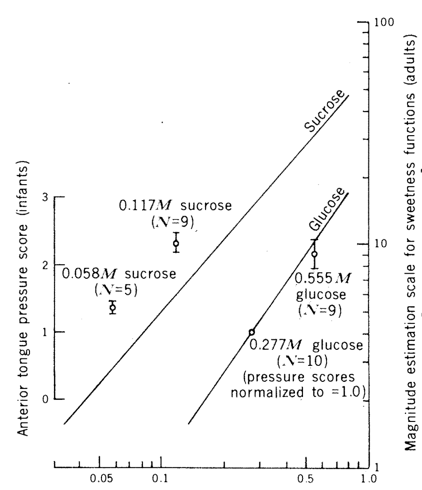

Fig. 2. The four data points are tongue pressure scores (left ordinate) for the four sugar solutions given to infants in this study. Standard errors are indicated by vertical bars. The two lines are psychophysical functions (right ordinate) for adults, from Moskowitz (*11*).

dicated around the three data points which are not constrained to 1.0 by this standardization procedure.

Two relationships are immediately apparent in these data. First, the amplitude of anterior tongue pressure, for both sugars, is a direct function of sugar concentration: as concentration doubles, there is a near doubling of tongue pressure. Second, at least at the concentrations we employed, sucrose is a more effective stimulus than is glucose. An idea of how this situation compares with adult responses to varying concentrations of these two sugars can be derived from the two sweetness magnitude estimation functions (*11*) superimposed on Fig. 2. There is a remarkable similarity in slope and in relative height between the psychophysical functions and those implicit in the four data points from the infant tongue pressure responses. Future work, of course, must include more than two concentrations of each sugar to determine more precisely the slope of the concentration function in the newborn.

We feel that two conclusions are justified on the basis of these observations. First, the sensory apparatus responsible for assessing relative sweetness of sugars is essentially as competent in the newborn as it is in the adult. Second, this sensory apparatus is capable of systematically eliciting a precisely graded response in the human newborn. The possibility that this graded response is reflexive in nature is enhanced by the report (*12*) of reflexlike lateral tongue movements from single drop gustatory stimulation in the newborn.

The relationship of these competencies to the problem of palatability and control of food intake in the newborn is one which has not yet been resolved. Simultaneous with our initial report of the relative effectiveness of these four solutions in controlling tongue movements (*9*), an independent investigation (*13*) reported similar results for sugar type and concentration in increasing amount of fluid ingested by newborns. The fact that the slopes relating concentration of sucrose and glucose to amount of fluid ingested were different from those reported here for tongue pressure could reflect the possibility that other factors than sweetness are involved in determining amount of fluid ingested, perhaps including the post-ingestional effects of the fluids. A subsequent study with newborns (*14*) counted number of sucks to sucrose and glucose concentrations presented either before or after water. No systematic effects of sugar type or concentration were found when water was offered first, but sugar type and concentration had a strong effect on number of sucks to subsequently presented water; newborns sucked less to water following stronger or sweeter sugars than following weaker or less sweet sugars. Since water has a sour-bitter taste to adults after adaptation of the taste buds to sugar (*15*), these results could be viewed as a demonstration of a similar phenomenon in the newborn, with stronger or sweeter sugars producing a stronger or more persistent effect on the subsequent water taste.

Thus, the ability of the newborn to utilize the gustatory apparatus to discriminate among ingestible substances has here been clearly demonstrated, and has been shown (*13*) to affect the amount the infant will ingest; however, the precise relationship between the infant's sensory and ingestive competencies has yet to be fully explored. One theoretical approach to this problem has been elaborated elsewhere (*8, 9*).

GEOFFREY H. NOWLIS*, WILLIAM KESSEN
Department of Psychology,
Yale University,
New Haven, Connecticut 06520

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* Present address: Rockefeller University, New York 10021.

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Measurement of an Inhibitory Zone

Abstract. *An inhibitory zone mechanism generates the heterocyst pattern in* Anabaena. *These inhibitory zones can be measured; we find that they extend about five cells on either side of a heterocyst. We can use our observations to predict with reasonable accuracy which cells in the filaments will differentiate into heterocysts.*

Little is known about the biochemical mechanisms that control biological spaced patterns, but a simple and attractive hypothesis is that the spacing is due to the production of an inhibitory compound by the elements of the pattern, which prevents other elements from forming too close to them. This hypothesis has been proposed in many cases where patterns are formed by the intercalation of new elements in a growing tissue, for example, insect bristles (*1*), leaf primordia (*2*), and stomata (*3*). The filamentous blue-green alga *Anabaena* is an ideally simple organism for testing the hypothesis. It has a spaced pattern of differentiated cells (heterocysts) formed by intercalation, and an inhibitory zone mechanism has been conjectured (*4, 5*). We now report that there are zones of a well-defined size around heterocysts within which other heterocysts do not develop, and also that these zones can reasonably be attributed to an inhibitory influence from the heterocyst.

The way that the alga grows and maintains its pattern can best be understood from a time-lapse sequence of part of a growing filament (Fig. 1). In the interval shown, the vegetative cells divide, increasing the distance between the two heterocysts. When this distance has roughly doubled, one of the vegetative cells becomes a proheterocyst (an early heterocyst) and eventually develops to maturity. Vegetative cell divisions are asymmetrical (*6*) and a heterocyst only develops from the smaller daughter of a division. Notice that this asymmetry produces an asynchrony in cell cycle stages along the filaments.

If there are constant inhibitory zones, *n*