Cardiac Indices of Infant Speech Perception: Orienting and Burst Discrimination*

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ABSTRACT

The present study investigated burst cue discrimination in 3- to 4-month-old infants with the natural speech stimuli [bu] and [gu]. The experimental stimuli consisted of either a [bu] or a [gu] burst attached to the formants of the [bu], such that the sole difference between the two stimuli was the initial burst cue. Infants were tested using a cardiac orienting response (OR) paradigm that consisted of 20 tokens of one stimulus (for example, [bu]) followed by 20 tokens of the second syllable (20/20 paradigm). An OR to the stimulus change revealed that young infants can discriminate burst cue differences in speech stimuli. Discussion of the results focused on asymmetries observed in the data and the relationship of these findings to our previous failure to demonstrate burst discrimination using the habituation/dishabituation cardiac measure generally employed with older infants.

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INTRODUCTION

The perception of speech involves the integration of overlapping acoustic cues in the form of a complex code, the primary unit of which has been defined as the syllable (Liberman, Cooper, Shankweiler and Studdert-Kennedy, 1967; Liberman, 1970). In syllables consisting of a stop consonant plus a vowel, a brief, initial burst of energy, and (in some stops) aspiration, typically precede the formant transitions and steady-state vowel components of the syllable. Although the importance of all of these components in adult speech perception has been investigated, perhaps the least studied and most controversial of these components has been the initial burst cue.

The burst cue consists of (i), a brief explosion (less than 20 msec) produced by the release of occlusion, and (ii) a very brief (0-10 msec) period of frication. The duration and frequency characteristics of the burst vary as a function of place of articulation, vowel context and voicing. The perceptual significance of the burst also varies as a function of these factors. For example, bursts contribute little to the identification of /b/ except, possibly, in back vowel environments; bursts contribute significantly to the identification of /d/ in front vowel environments, but relatively less in center and back vowel environments; and bursts are generally important for identification of /g/ (for details see Fischer-Jørgensen, 1972; Dorman, Studdert-Kennedy and Raphael, in press). Bursts, then, are important cues for stop consonant recognition.

In a recent study by Morse, Leavitt, Miller and Romero (in press), adult burst discrimination was investigated using a nonverbal, cardiac measure. In this study a heart-rate (HR) orienting response (OR) habituation-dishabituation procedure was used in assessing the discrimination of a natural [bu] ([bu] burst + [bu] formants) and a transposed [gu], consisting of a [gu] burst attached to the same [bu] formants. In the type of paradigm employed by Morse et al., the subject is presented with repeated trials of a familiarization stimulus followed by 1 or 2 trials of a change stimulus. To allow for recovery of a cardiac response to trial offset, the intertrial intervals (ITI) in this paradigm typically vary between 25 and 60 secs. In the Morse et al. study, subjects received 8 trials [each consisting of 3 stimuli with an interstimulus interval (ISTI) of 1 sec] of the familiarization stimulus (either [bu] or [gu]) followed by 2 trials of the change stimulus. Intertrial intervals (offset to onset) varied randomly between 25 and 35 sec. In this study, habituation of the cardiac component of the orienting response (HR deceleration) to trial onset was observed across the familiarization trials. Dishabituation (recovery of the orienting response) was found to occur in response to the onset of the change trials, thereby indicating discrimination of those burst cues. In addition, this cardiac evidence of discrimination was accompanied by verbal reports of discrimination.

If bursts do play such an important role in adult speech perception, then it is of interest to examine the developmental course of their importance beginning in early infancy. Research on infant speech perception has shown that by four months of age, infants can already discriminate formant transition and steady-state vowel information in a manner similar to the adult's perception of these cues (for example, Eimas, Siqueland, Jusczyk and Vigorito,
Figure 1: HR difference score data from the 8/2 procedure. Ten trials are grouped into 5 trial blocks of 2 trials each (Miller, et al., 1975a).
1971; Eimas, 1974, 1975a; Miller, 1974; Miller and Morse, 1975; Swoboda, Morse and Leavitt, 1976; Till, 1976). In contrast, no comparable data are yet available on the infant's ability to discriminate differences in the burst component of the syllable. Since variations of the cardiac habituation-dishabituation paradigm described above have been successively employed in several studies of infant auditory discrimination (Moffitt, 1971; Berg, 1972; Lasky, Syrdal-Lasky and Klein, 1975), an earlier study (Miller, Morse and Dorman, 1975) attempted to investigate infant burst cue discrimination using the same heart rate procedure and stimuli employed in the Morse et al. (in press) adult study. The 3- to 4-month old infants in this study (hereafter referred to as Miller et al., 1975a) were presented with 8 trials of either [bu] or [gu] and 2 trials of the change stimulus. The cardiac data from this study are depicted in Figure 1. In this figure, the 10 trials of the 8/2 procedure are grouped into 5 trial blocks (TB) of 2 trials each. Analyses of variance for trends over seconds and trends over trials performed on these data confirmed the observation of a reliable orienting response (OR) to trial onset on the first few trials (TB 1-3) that subsequently habituated over trials. However, dishabituation on the change trials (TB 5) was not observed, thus suggesting that these infants were not capable of discriminating this burst contrast (for additional details of the methodology and results of this study, cf. Miller et al., 1975). However, recent developmental studies of infant auditory discrimination suggest that this conclusion may be premature. Although infants older than 4 months of age have been found to readily exhibit auditory discrimination with variations of the 8/2 cardiac OR paradigm (Moffitt, 1971; Berg, 1974; Lasky, et al., 1975), infants between 6 weeks and 12 weeks have failed to demonstrate auditory discrimination when these paradigms were employed (Berg, 1974; Brown, Leavitt, and Graham, 1975; in press; Leavitt, Brown, Morse and Graham, in press). For example, Brown et al. (1975) recently employed a 6/2 cardiac paradigm (6 familiarization trials, 2 novel trials) in assessing the discrimination of an auditory change in 12-week old infants. As in the Miller et al. (1975a) study, Brown et al. (1975) observed significant orienting and habituation, but no dishabituation to a stimulus change.

In contrast to the failure of infants less than 4 months of age to evidence auditory discrimination using an habituation-dishabituation cardiac paradigm, several investigators have reported auditory/speech discrimination in infants as young as 4 weeks of age using an operant high-amplitude sucking paradigm (Eimas, Siqueland, Jusczyk and Vigorito, 1971; Trehub and Rabino-vitch, 1972). Consequently, the absence of discrimination in the present experiment (and in the Brown et al., 1975, study) may more likely reflect a developmental limitation of the habituation-dishabituation paradigm, rather than an inability of young infants to discriminate burst cues. A recent study by Leavitt et al. (in press) further supports this suspicion. Leavitt et al. failed to obtain auditory discrimination in 6-week olds using a 6/2 paradigm, but when a cardiac paradigm was employed in which the intertrial intervals of the habituation/dishabituation procedure were eliminated (a no-ITI paradigm), 6-week olds did exhibit auditory discrimination.

In sum, this developmental pattern of heart rate results suggests that the 3- to 4-month old infants' competence in discriminating burst cues may be better assessed with a no-ITI cardiac paradigm than with an habituation-
dishabituation cardiac procedure. Therefore, the present experiment employed
a no-ITI paradigm similar to that used by Leavitt et al. to investigate
further the burst discrimination of 3-4-month old infants. In this study 20
tokens of one syllable (for example, [bu]) were followed immediately by 20
tokens of a change syllable ([gu]) and discrimination was indexed by an OR to
the stimulus shift.

METHOD

Subjects

Twelve infants, aged 3-4 months (mean = 3 mos, 1.5 wks), served as
subjects. The participation of parents in the greater Madison area was
solicited by a letter describing the research and a follow-up phone call. A
total of 29 infants was tested with 14 (48 percent) eliminated on the basis of
predetermined state criteria, 2 because of equipment problems, and 1 due to
experimenter error. The 12 remaining infants included 5 males and 7 females.

Apparatus

Each subject was tested in an infant seat positioned on a table-like
platform in an Audio-Suttle sound-attenuated chamber. Throughout the session,
the parents and experimenter were able to monitor visually the infant's
behavior over a closed-circuit television system. Stimuli were played to the
subject on a TEAC 3300S 2-track tape deck coupled to a Bogen Challenger
amplifier and Hewlett-Packard attenuator. An Acoustic Research 2 ax speaker,
located 40" in front of the infant, presented the stimuli at 70 ± 1 dB (A) SPL
against a background level of 27 dB (A). Sound level measurements were made
with a General Radio Sound Level Meter (#1551-C, microphone #1560-P5) placed
at the site of the infant's head.

A stimulus artifact on the second channel of the stimulus tape, denoting
stimulus onset and change, occurred coincident with the first and twenty-first
stimuli of each 20/20 trial. A Scientific Prototype audio threshold relay
detected the stimulus artifact and converted it into a suitable pulse for
recording on one channel of a Sony TC 756 2-track tape deck. Cardiac activity
was detected by Beckman biopotential miniature skin electrodes and amplified
by a Gilson polygraph. The two active electrodes were placed 2-3 cm above the
right nipple and approximately 2-3 cm above and to the left of the navel. A
ground electrode was placed 2-3 cm above the left nipple. Sites for electrode
placement were prepared with alcohol and the electrodes were attached with
either Beckman or Beck-Lee paste and micropore tape. An adjustable pulser
converted each R wave in the electrocardiogram (EKG) into a square pulse
suitable for recording on the second channel of the Sony TC 756 tape deck.

1Of the 14 infants rejected for state, 10 had at least one behaviorally
acceptable trial. Thus, only 4 infants (15 percent) did not contribute
acceptable data for the first trial, suggesting that because of the low
attrition rate this paradigm is a desirable one for infant researchers.
Stimuli

The natural speech stimuli [bu] and [gu], produced by an adult male speaker, were used in constructing the experimental [bu] and [gu] stimuli shown in Figure 2. The experimental [bu] was the natural [bu] initially produced by the speaker. The experimental [gu] was produced by removing the burst portion from the natural [bu] and replacing it with the burst portion of the natural [gu]. This experimental stimulus was consistently identified as a [gu] by over 50 adult Ss. The duration of the [bu] was 450 msec with an 8 msec burst, whereas the 474 msec [gu] contained a 32 msec burst. The construction and recording of the stimuli were carried out on the PCM system at Haskins Laboratories (Cooper and Mattingly, 1969). These were the identical stimuli employed in the Miller et al. (1975) study.

Procedure

Upon arrival at the laboratory, the parents were briefed on the procedures and purposes of the research and their consent was solicited prior to the test session. The infant was then placed in the infant seat in the testing chamber and the electrodes were affixed to the infant's chest. When the infant was judged to be in a quiet, alert state, stimulus presentations began. The general parameters of the 20/20 paradigm and the orders presented to subjects are depicted in Table 1 together with the contrasting features of the 8/2 procedure employed in the Miller et al. (1975) study. As can be seen in Table 1, each subject was presented with 4 20/20 sequences (ISI = 1 sec), each separated by a 30-second pause. The order of stimulus change within the four trials was alternated from [bu] → [gu] to [gu] → [bu] (or vice versa) and the order of presentation on the first trial was counterbalanced across subjects, such that half of the subjects received a [bu] → [gu] shift on trial 1 (Group A) and half a [gu] → [bu] shift (Group B). The duration of each 20/20 sequence was 1 minute and that of the entire experimental session approximately 5.5 minutes.

Throughout the session, an assistant seated inside the chamber and out of the infant's sight observed and recorded the infant's behavior using a closed-circuit TV monitor. Behavior recording occurred for 5 seconds prior to and 10 seconds following each trial onset and change and included visual behavior (for example, fixation, eye widening), body movements, vocalization, sucking behavior, and states of arousal (for example, fussy, drowsy, alert). Subjects were eliminated from the study only if they exhibited excessive fussiness, drowsiness, and/or large movements during the behavior recording periods (cf. Leavitt, 1975, for further details of recording and acceptance criteria).

Data Reduction

Each R wave of the infant's EKG was recorded as a square pulse on audio tape and the R-R (interbeat) intervals for 5 prestimulus and 15 poststimulus seconds were computed by a PDP-12 computer. These data were then converted by a Datacraft computer into a beats-per-minute (bpm) measure for each pre- and poststimulus second. Prestimulus level was calculated for one second prior to each trial onset and change. Analyses were performed on difference scores calculated by subtracting this prestimulus level from each of the subsequent

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Figure 2: Oscillograms of the experimental [bu] and [gu] stimuli.
TABLE 1: General parameters of the 20/20 HR discrimination paradigm of the present study and the 8/2 habituation-dishabituation paradigm employed by Miller et al. (1975a).

<table>
<thead>
<tr>
<th>Parameters</th>
<th>8/2 Paradigm</th>
<th>20/20 Paradigm (present study)</th>
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<td>ISI=1 sec</td>
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<td>ISI=1 sec</td>
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<td>ITI=25-35 secs</td>
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Presentation Orders

A  BU → GU    B  GU → BU

A  1  BU → GU    B  1  GU → BU
2  GU → BU    2  BU → GU
3  BU → GU    3  GU → BU
4  GU → BU    4  BU → GU
15 poststimulus seconds. F-tests were performed by a Datascraft computer on the mean difference scores to determine significant departures from prestimulus level for each poststimulus second and trend analyses were carried out by a UNIVAC 1110 computer.²

RESULTS

Onset Data

The onset data of the 20/20 procedure are displayed for the two orders of presentation on trial 1 (as detailed in Table 1) in Figure 3. These data were subjected to an analysis of variance for trends with Order of Presentation on trial 1 (A = [bu] → [gu] vs B = [gu] → [bu]) as a between-subjects factor and within-subjects factors of Shift Condition within the 4 trials ([bu] → [gu] vs [gu] → [bu]), Trial Blocks (TB 1 = trials 1 and 2 vs TB 2 = trials 3 and 4), and Seconds (15).

A reliable orienting response to onset over all trials was shown in the significant quadratic trend over Seconds, \( F(1,10) = 42.46, p < .001 \). Furthermore, a significant main effect for Trial Blocks, \( F(1,10) = 6.6, p < .01 \), suggested that the initial OR habituated from the first to the second half of the session. Although no significant main effect for Order of Presentation was obtained, a significant quadratic trend over Seconds x Order x Condition interaction, \( F(1,10) = 23.07, p < .001 \), was observed. In addition, the quadratic trend over Seconds x Condition x Trial Blocks interaction, \( F(1,10) = 7.75, p < .025 \), was also found to be reliable. As can be seen in Figure 3, these interactions indicate that the magnitude of the initial orienting response varied in the two orders of initial presentation as a function of stimulus shift and the first vs. the second half of the session.

Change Data

The change data are separated for the two orders, A and B, in Figure 4. F-tests on the difference scores of these data revealed that orienting occurred on every trial in which there was a [bu] → [gu] shift (trial 1, \( p < .01 \); trial 2, \( p < .05 \); trial 3, \( p < .01 \); trial 4, \( p < .050 \).³ In contrast, no significant orienting (or acceleration) occurred on those trials in which there was a [gu] → [bu] shift. A 4-way analysis of variance identical to that employed for the onset data, was performed on the change data and confirmed the existence of differential responding to the stimulus change. A significant main effect of Shift Condition, \( F(1,10) = 6.05, p < .05 \), a significant Seconds x Shift Condition interaction, \( F(14,140) = 2.75, p < .005 \), and a significant cubic trend over Seconds x Shift Condition interaction,

²Wilson's (1974) CARDIVAR package was employed in preparing the R-R interval data for subsequent analyses. The F-test and trend analysis programs were developed and generously made available to us by Dr. F. K. Graham.

³All significance levels for these F-test analyses were converted to the Bonferroni t (Myers, 1972).
Figure 3: Onset data for the 4 20/20 trials, grouped according to initial shift condition. (A = [bu] → [gu] on trial 1 vs. B = [gu] → [bu] on trial 1)
Figure 4: Change data for the 4 20/20 trials, grouped according to initial shift condition. (A = [bu] → [gu] on trial 1 vs. B = [gu] → [bu] on trial 1). Broken lines = [gu] → [bu] shift trials; solid lines = [bu] → [gu] shift trials.
\( F(1,10) = 19.25, p < .005 \), all indicated that there were different responses to the two types of stimulus change. The absence of any order effects confirmed the consistency of the stimulus shift effects across both orders A and B.\(^4\)

**DISCUSSION**

**Asymmetry in Discrimination**

Two possible interpretations that may be offered for the asymmetry observed in this study are related to the construction of the experimental stimuli. The first possibility is that the [gu] stimulus may have been more salient to the infant, and therefore a greater elicitor of orienting. The [gu] burst, relative to the [bu] burst, is slightly longer in duration, has a greater energy concentration within a more restricted frequency range, and is acoustically incongruous with the [bu] formant transitions which follow. Any or all of these features may have enhanced the saliency of the [gu] stimulus.\(^5\)

A second possibility is that during the first 20 stimuli, the burst cue is being adapted in a manner similar to that reported in adults for a variety of other speech cues, including bursts (Eimas and Corbit, 1973; Ades, 1974; Cooper, 1974; Blumstein and Stevens, 1975; Diehl, 1975; Gatong, 1975; Tarttter and Eimas, 1975; Morse, Kass and Turkienicz, 1976). In the present study, if the [gu] burst is adapted, the remaining cues of the experimental [gu] stimulus are the formant transitions of the [bu]. Consequently, if adaptation occurs within the first 20 stimuli, the [gu] stimulus would become a [bu], and hence the shift to [bu] might not be discriminable. In contrast, when the [bu] burst adapts, a [bu] remains and would be discriminated from a shift to [gu]. Although adult studies of speech adaptation have not attempted to determine whether reliable adaptation effects can occur within only 20 presentations of a stimulus, this possibility cannot be ruled out, either in the adult or in the infant.

Although the asymmetry observed in the present study was not anticipated, asymmetries in infant speech discrimination have also been reported elsewhere (Butterfield and Cairns, 1974). Since Eimas (1975b) has suggested that the process of adaptation may be responsible for much of the evidence of infant

\(^4\)Subsequently, a group of 12 infants was tested in a control condition (no stimulus change), that included one 20/20 trial of either [bu] or [gu]. F-tests and trend analyses performed on these data revealed no significant cardiac deceleration following the twenty-first stimulus. These data confirm the conclusion that the OR recovery to the [bu] + [gu] shifts actually reflected burst discrimination, rather than cyclic changes in cardiac activity.

\(^5\)Although inspection of Figure 3 suggests that greater onset orienting did occur to the [gu] stimulus, there is no statistical support for this observation. However, a similar study of infant burst discrimination by Miller, Goy, Morse and Dorman (1975) did find statistical evidence of greater initial orienting to [gi] and [bil], using burst stimuli constructed in a manner similar to those of the present study.
speech discrimination obtained with the nonnutritive sucking paradigm, more direct tests of this adaptation account using infant paradigms with adult listeners may greatly aid in elucidating the mechanisms responsible for these asymmetries.

**Discrimination: 8/2 vs. 20/20 Paradigm**

The major implication of the present experiment is that infant burst discrimination is dependent upon the particular paradigm employed. These results revealed that infants are capable of this discrimination when tested with the 20/20 paradigm, yet do not appear so within the 8/2 paradigm (Miller et al., 1975a). Since no study has reported cardiac dishabitation to auditory stimuli in infants younger than 4 months, it is possible that the lack of evidenced discrimination in the Miller et al. (1975a) study may reflect an inability of young infants to demonstrate OR dishabitation to any change in auditory stimulation. This interpretation is consistent with the data reported by Brown et al. (1975, in press) that suggest developmental trends in the characteristic properties of orienting behavior (that is, initial OR, habituation, dishabitation) to auditory stimuli. However, since Adkinson and Berg (1974) have observed cardiac dishabitation to visual stimuli in newborns, this conclusion remains somewhat tenuous.

Perhaps the more productive way of interpreting the difference between these two studies would be to examine the physical parameters of the two paradigms employed (cf. Table 1). Two obvious parametric differences resulting in the different stimulus distributions of these two paradigms are: 1) the number of familiar stimuli preceding the stimulus shift, and 2) the ITI's separating blocks in the 8/2 procedure, which are absent in the 20/20 paradigm. Since there are actually fewer tokens of the familiar stimulus presented to the infant prior to the change in the 20/20 paradigm (20, as opposed to 64 in the 8/2 procedure), any differences in memory for the familiar syllable cannot be due to the total number of prechange exemplars.

If, instead, the ITI's of the 8/2 paradigm were primarily responsible for the different results obtained in these two experiments, then it may be because these lengthy silent intervals in some manner imposed too great a burden upon the infant's processing of these burst stimuli. In other words, the distribution over time of the stimuli in the 8/2 procedure may have resulted in less consolidation of the stimulus being stored in memory and/or some decay during the ITI of the "neuronal model" (Sokolov, 1963) of the burst stimulus. Consequently, the habituation observed in the 8/2 paradigm may have reflected the development of a more general model of the stimulus presented, and thus the absence of discrimination in this paradigm is not surprising. Unfortunately, the development of a parametric research program to answer these questions may be complicated by several factors. First, the general parameters of the habituation-dishabituation paradigm were originally conceptualized to include recovery time between trials for an OR to stimulus offset. In addition, some recent work (Roth and Morse, 1975) suggests that for speech sounds, an infant's orienting response to initial stimulus onset may require some 20-30 seconds for recovery. Thus, one cannot simply vary the ITI between blocks of stimuli in moving from a 20/20 paradigm to an 8/2 procedure. Although the results of the present study do not resolve these questions about
the processes underlying cardiac measures of infant discrimination, they do
demonstrate that with one cardiac paradigm, burst discrimination does occur in
early infancy.

In conclusion, the results of the present experiment have several
implications for our understanding of the development of infant speech
perception. First, they reveal that young infants can discriminate very brief
burst cues in stop consonants, thus adding to the list of important acoustic
events in the speech signal to which infants are sensitive at a very early
age. Second, the consistent pattern of asymmetry suggests that more direct
tests of adaptation proposals for infant (and adult) burst discrimination may
greatly enhance our understanding of the mechanisms that underlie infant
speech perception. Third, the burst discrimination obtained with the 20/20
procedure of the present study suggests (as Leavitt et al. observed) that a
no-ITI paradigm may be more useful in studying the speech discrimination of
infants younger than 4 months than the more traditional habituation-dishabituation
procedure. The recent evidence of categorical discrimination for place of
articulation using the 20/20 paradigm in 3- to 4-month-old infants (Miller
and Morse, 1976) further underscores the usefulness of this paradigm in
studying infant speech discrimination.

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