ON USING INTENSITY AS A CODING PARAMETER IN TACTILE SPEECH STIMULI: PSYCHOPHYSIOLOGICAL DISCRIMINABILITY EFFECTS

H. G. Piroth and S. Gfroerer

Institut für Phonetik und Sprachliche Kommunikation
der Universität München, Germany

ABSTRACT

In preparation of a system that uses intensity as a coding parameter for tactile speech this paper reports an investigation of two general psychophysiological effects that show to be involved in intensity perception, namely the order effect and masking.

1. INTRODUCTION

Not only in psychophysiology, but also in application-oriented research to establish electrotactile speech transmission systems for the deaf questions concerning the human ability for tactile intensity perception have an important role. In developing an electrocutaneous speech-to-skin communication aid that transmits articulation-based features [13] we assume that a suprasegmental component (stress, intonation) could be added to the feature coding method by superimposing intensity variations on the segmental stimuli [9].

Classical investigations on electrotactile intensity perception discuss the number of possible steps that can be discriminated between absolute threshold and pain. Lindner 1937 [5] has reported that the pain threshold is reached at approximately four times absolute threshold. At a frequency of 400 Hz he situates absolute threshold at about 0.8 mA, pain threshold at 4.7 mA with 27 discriminable steps in between. Schöbel 1936 [11] determined a difference limen of 4 to 5% in normal hearing subjects, Anderson and Munson 1951 [1] of 2 to 5% in the frequency range between 100 and 5000 Hz. Hawkes 1959 [4] measured a limen of 5.3% at an intensity of 120% and of 3.8% at 200% above absolute threshold.

A pilot experiment with more complex stimuli [10] using electrocutaneous pulse train sequences showed that at least two different intensity levels can be identified after a short training period. The present experiment was conducted to gain more knowledge on the discriminability of tactile intensities in complex stimuli. Especially, dependency effects of intensity perception on the temporal and spatial stimulus structure were investigated.

2. APPARATUS

The test stimuli were constructed and presented with the 16-channel System for Electrocutaneous Stimulation SEHR-2. Four rows of electrode pairs were fixed along the dorsal, ulnar, volar, and radial sides of the Ss' left forearm. (See [13] for details and illustrations.)

3. STIMULI

Four complex stimuli were constructed with pulse train sequences as their basic part consisting of three bipolar pulses with a rectangular part in one and hyperbola-shaped part in the other polarity, resulting in a d.c.- component equaling 0. The pulse repetition rate was 400 Hz. In stimulus I eight pulse trains were delivered surrounding the arm at four distal electrode pairs with two succeeding pulse trains at each place and a constant interval of 15 ms after each of the eight pulse trains. The pattern started at the ulnar side of the arm and proceeded to the dorsal side. Then, without an additional pause a longitudinal sequence of pulse trains was presented oscillating between the distal electrode pair on the dorsal side and the neighbouring dorsal electrode pair fixed 4 cm apart in proximal direction. This sequence started at the more proximal place and consisted of eight pulse trains separated by an interval of 20 ms after each pulse train.

In stimulus II the order of the two parts was changed, thus it started with the longitudinal part and ended with the surrounding one. For stimulus III the complete surrounding part of the pattern was presented to the ring of electrode pairs placed 4 cm apart from the distal ring in proximal direction. The longitudinal part that followed remained the same as in stimulus II, but started from the distal electrode pair.

In stimulus IV again, the order of the two parts of stimulus III was altered.

According to the feature coding method discribed in [13] stimuli I to IV are the tactile equivalents of /fi:/, /i:f/, /ʃi:/, and /i:ʃ/. To determine stimulus intensities each S underwent a calibration procedure before each test. The Ss had to adjust absolute threshold and the threshold of annoyance four times for each place of stimulation in a mixed ascending and descending procedure using the basic parts of the stimuli presented repeatedly and separated by an interval of 50 ms. Nine intermediate intensity values were calculated corresponding to the absolute threshold +10%..., +90% of the difference between both thresholds. Accordingly, seven versions of the five stimuli were defined with the intensity of the rectangular parts of the pulses in the vowel pattern (i.e. the longitudinally moving part) set to the 3rd to 9th intensity value as calculated. The intensity of the consonantal pattern (the surrounding one) was two steps (20% of the threshold difference) lower than that of the vocalic part.

4. PROCEDURE AND SUBJECTS

Stimuli were arranged in pairs to yield a two-step discrimination test for stimulus intensities. All pairs contained two repetitions of the same stimulus with an interval of 1 s within the pair. Five pairs were built for each stimulus with higher intensities in the second stimulus (intensity values 3-5, 4-6, 5-7, 6-8, 7-9) and the five corresponding pairs with lower intensities in the second stimulus.

In this way a 4x2x5-factorial test design was constructed with 4 stimuli, 2 orderings (ascending and descending intensities) and 5 intensity levels.

One subtest included 10 repetitions of pairs of stimuli I and II (/fi:- fi:/ and /i:f-i:f/) in randomized order, the other subtest of stimuli III and IV (/ʃi:-ʃi:/ and /i:ʃ-i:ʃ/), resulting in 200 pairs for each subtest. The interval between the pairs was set to 4 s.

Eight Ss participated in the experiment. They received both subtests in different sessions with the order of subtests randomized over Ss. Each subtest was presented in two parts of 100 pairs with a short break in between. Ss were informed that the intensity differences were encoded in the "vocalic part" of the stimuli and had to mark the more intensitive stimulus of each pair on an answer sheet.

5. RESULTS

Tab. 1 gives the results of a 4x2x5-factorial MANOVA (SPSS; [6] 1975) with stimulus, ordering and intensity level as factors. The overall discriminability was 80.53% showing that the intensity differences were well-recognizable. The MANOVA calculation yielded a significant stimulus effect ($p<0.05$) and a highly significant interaction of intensity level and ordering ($p<0.001$). It can be seen from Fig. 1 that dicriminability increases with intensity level for the series of ascending pairs (higher intensity in the second stimulus), but decreases with higher intensity level for descending pairs, thus producing the interaction effect. Concerning the main effect of the factor 'stimulus' a DUNCAN a posteriori test showed significant differences ($p<0.05$) between /ʃi:/ and /fi:/, as well as between /ʃi:/ and /i:ʃ/, and /ʃi:/ and /i:f/. /i:f/ and /i:ʃ/ showed a slight ($p<0.10$) tendency effect (Tab. 2).

Table 1
Results of the Statistical Analysis

Factor	d.f.	F	p	
ITEM	19,1	7.63	=0.04	*
ORDERING	19,1	0.09	=0.78	n.s.
LEVEL	19,4	2.44	=0.07	n.s.
IT x ORD	19,1	0.37	=0.59	n.s.
IT x LE	19,4	0.58	=0.67	n.s.
ORD x LE	19,4	12.42	<0.001	***
ITxORDxLE	19,4	1.00	0.42	n.s.

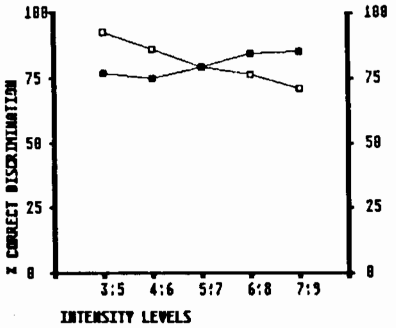

Figure 1: Discriminability dependent on intensity levels (full squares: ascending; open squares: descending)

6. DISCUSSION

The interaction of intensity level and ordering shows an order effect as it is known from classical investigations on the perception of temporal durations (e.g. [12]). In general, this so-called time-order- error produces discrimination rates that are dependent on the order of the stimuli and on the duration of the inter-stimulus interval between them. A similar effect in the discrimination of the durations of tactile stimuli was found by Piroth&Tillmann 1987 [8], thus it is clear now that duration as well as intensity perception of electrotactile stimuli is affected by time-order-error.

The asymmetric dependency of discrimination rate on the kind of stimulus presented, is more difficult to explain, namely the significantly low results for stimulus /ʃi:/.

The rank order of the stimuli shows that intensity discrimination tends to be better with /f/ than with /ʃ/ and better with VC than with CV. Similarly, Piroth 1986 [7] had shown that identification of tactile vowels is higher in VC and identification of consonants is higher in CV-syllables. Those effects

Table 2

Discrimination Dependent on Stimuli

	/i:f/	/fi:/	/i:ʃ/	/ʃi:/
%	83.88	81.49	81.00	75.75

/i:ʃ/ > /ʃi:/

/fi:/ > /ʃi:/

/i:f/ > /ʃi:/

could be explained under the assumption of forward masking. Since according to the earlier investigations there is a tendency to forward masking and since intensity variations to be discriminated in the present experiment are encoded into the "vocalic" part of the stimuli, intensities of VC-stimuli should be more easily discriminated. The poor recognition in /ʃi:/ could then be explained if /ʃ/ had a stronger masking effect than /f/ in CV- stimuli. For such an explanation the central representations of the stimuli instead of their peripheral characteristics have to be taken into account. Within the frame of this experiment only a first speculative approach to such an explanation can be proposed: The basic units of the stimuli (pulse trains) were identical in all cases, but they differed in their temporal and spatial relations. Because of the somatotopic representation of body sites the spatial relations should be preserved in building the central representation. But since more distal and more proximal places were stimulated in the "consonantal" (circumferent) parts of the stimuli, the conduction velocities in the nerve fibres may become relevant to determine the central temporal relations.

In CV-stimuli the interval between the last pulse train of /f/ or /ʃ/ and the first of /i:/ is 15 ms. The distance between the corresponding places of stimulation is 4 cm, but in /fi:/ the place changes in proximal, in /ʃi:/ in distal direction when proceeding from the "consonantal" to the "vocalic" part. Relying on the values given in the literature ([2,3]) conduction velocity in thick myelinated fibres is between 40 and more than 100 m/s, i.e. even with 40 m/s a distance of 4 cm in the distal-proximal direction produces a change of the temporal intervals of only 1 ms which is too small to cause an effect as observed. But if - as can be supposed - a part of the central representation of the stimuli is based on information processed via thin unmyelinated C- fibres with a conduction velocity of no more than 2.55 m/s the temporal intervals at the points of central occurance of two successice pulse trains at places 4 cm apart from one another differ from the peripheral interval by at least 15.7 ms. Thus, in /ʃi:/ with

/ʃ/ being presented at more proximal places the inter-pulse-train interval is centrally doubled (15 ms + 15.7 ms = 30.7 ms), and in /fi:/ starting at the distal places it is reduced to approximately 0 (15 ms - 15.7 ms = -0.7 ms).

Based on this speculative assumption one could conclude:

(i) /i:ʃ/ and /i:f/ cannot cause forward masking, since the vocalic part is presented first (81.00% and 83.88% correct discrimination).

(ii) /ʃi:/ produces a forward masking effect, since the central representation of /ʃ/ is built up before the representation of /i:/ is evoked (thus, only 75.75% correct answers).

(iii) For /fi:/, the representation of both parts are not separate, but as the central point of occurrance of the last pulse train of /f/ is nearly identical with that of the first in /i:/ the whole stimulus elicits a unique, more complex representation which is not affected by forward masking (81.49% correct answers).

To summarize, the stimulus effect can be explained in terms of central temporal characteristics if C-fibre conduction contributes to the representation of the stimuli used and if forward, but not simultaneous masking is involved in a perceptual process that separates the longitudinal and circumferent parts of the patterns. To evaluate this proposal, more specific electro- or psychophysiological experiments are mandatory.

7. REFERENCES

[1] ANDERSON, A. & MUNSON, W. (1951), "Electrical excitation of nerves in the skin at audiofrequencies", *J.Acoust. Soc.Am. 23*, 155-159.

[2] BURGESS, P. & PERL, E.(1973), "Cutaneous mechanoreceptors and nociceptors", in: A. Iggo(ed.), *"Handbook of sensory perception II. Somatosensory system"*, 29-78.

[3] GASSER, H.(1955), "Properties of dorsal root unmedullated fibers on the two sides of the ganglion", *J.Gen.Physiol. 38*, 709-728.

[4] HAWKES, G.(1959), "Cutaneous discrimination of electrical intensity", *Phil. Diss.* Univ. of Virginia.

[5] LINDNER, R.(1937), "Physiologische Grundlagen zum elektrischen Sprachetasten und ihre Anwendung auf den Taubstummenunterricht", *Z.Sinnesphysiol. 67*, 114-144.

[6] NIE, N. et al.(1975), *"SPSS Statistical Package for the social sciences"*, New York.

[7] PIROTH, H.(1986), "Electrocutaneous syllable recognition using quasiarticulatory coding of stimulus patterns", *J.Acoust.Soc.Am. 79, Suppl.1*, S73.

[8] PIROTH, H. & TILLMANN, H. (1987), "An order effect in pulse train discrimination as a case of time order error", *Proc. 11th ICPhS, Vol. 5*, 50-53, Tallinn.

[9] PIROTH, H.(1989), "Tactile recoding of phonological features in a system for electrocutaneous substitution of speech for the deaf", *Magyar Fonetikai Füzetek 21*, 188-191.

[10] PIROTH, H.(1991), "Intensity discrimination and identification in electrotactile pulse train sequences", to appear in *Forschungsberichte des Instituts f. Phonetik u. Sprachl. Komm. Univ. München (FIPKM) 29*.

[11] SCHÖBEL, E.(1936), "Versuche über Intensitätsunterscheidung beim 'elektrischen Tasten' verschiedener Frequenzen", *Z.Sinnesphysiol. 66*, 262-273.

[12] STOTT, L.(1933), "The discrimination of short tonal durations", *Diss.* Univ. of Illinois.

[13] PIROTH, H. & TILLMANN, H. (1991), "Articulation-based tactile speech for the deaf: a complete set of tactile segmental features for German", *Proc. 12th ICPhS*.