# AN ORDER EFFECT IN PULSE TRAIN DISCRIMINATION AS A CASE OF TIME ORDER ERROR

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## ABSTRACT

During tactile discrimination tests using the System for Electrocutaneous Stimulation SEHR-2', an order effect was revealed: sequences of pulse bursts with constant, small intervals between each two of them were presented in pairs. If these sequences had different intervals, S's discriminated better when the sequence with the larger interval was presented first. In the present investigation the effect was tested systematically in a four-factorial design. A univariate analysis of variance confirmed the order effect, but also showed that discrimination rate is nearly unaffected by variations of the inter-stimulus interval.

## INTRODUCTION

In order to establish a system for electrocutaneous speech transmission dynamic pulse train patterns must be designed that serve as basic stimuli' for the construction of tactile speech analogues (Piroth 1986 [6]). Those patterns should be readily discriminable and identifiable in a way that is analogous to the perception of natural speech. The System for Electrocutaneous Stimulation' SEHR-2 produces current-controlled bipolar electric impulses with freely variable intervals of the form shown in Fig. 1 of Piroth/Tillmann (1984) [7]. This study proved that continua of pulse train sequences that only vary the intervals between pulse bursts can produce a category switch in an identification test, if the threshold of coincidence for successive pulse bursts is crossed along the stimulus continuum: continuous movement' on the skin is clearly distinct from discrete taps'. Tests with a wide-spread continuum and a 20 ms-step between the neighboring items indicated a threshold at approximately 18 ms. Tillmann/Piroth (1986) [10] revealed an order effect in the discrimination of those stimuli: sequences of nine pulse bursts ( taps') consisting of three impulses each with constant, small intervals (ITI) between each two of them were presented in pairs. Then, if these sequences had different ITIs both shorter than 50 ms, Ss discriminated better when the one with the larger ITI was presented first. The effect could also be reproduced in the auditory mode using sequences of nine short tones and it vanished when, instead of the number of tones, the overall duration of the sequences was kept constant in long tone sequences (2.5 s). Yet, it was not clear, whether the disappearance of the effect was caused by the constancy in overall duration or because there are other parameters governing the perception in a test using sequences with a duration of more than 2s.

The present investigation uses a 2IAX-discrimination experiment to test the dependence of discriminability on the factors inter-tap interval' (ITI) step'(ITI(B)-ITI(A)), order of presentation'(OC), inter-stimulus interval'(ISI) in a 5.2.3.3-factorial design so that the nature of the order effect and the role of the threshold for coincidence of successive stimuli can be evaluated based on an interpretation of significant effects revealed by the experiment.

## STIMULI

Three pairs of gilded brass electrodes (9 mm in diameter with a minimal distance of 1 mm between the electrodes of a pair) were fastened to the dorsal side of the left forearm. They were arranged linearly so that the distal pair was 3 cm from the wrist, the medial and proximal ones 4 and 8 cm away from the distal one. Sequences of nine taps' consisting of three impulses with an impulse width of 200 µs and an inter-impulse onset interval of 2.5 ms each were delivered to the skin. The distal electrode pair received taps 1 - 3, the medial one taps 4 - 6, and the proximal one taps 7 - 9. The sequences differed in the duration of the inter-tap interval (ITI) between the successive taps only.

## PROCEDURE

The six Ss participating in the experiment first underwent a calibration procedure to adjust subjective intensity to a mid value between absolute threshold and unpleasentness. Since the 2IAX-test paradigm was used, the tap sequences were arranged in pairs and Ss had to decide whether stimuli were same' or different' (The arrangement of the factorial parameters is shown in Tab. 1). Each test of the experiment to a third contained pairs of AB-sequences being different with ITI(A) < ITI(B) ( first ordering condition' - 1st OC), to one third BA-pairs ITI(B) > ITI(A) (2nd OC), and to one third AA-pairs with ITI(A)=ITI(A) (3rd OC) ITIs of the sequence with the smaller interval were 5, 10, 15, 20, and 25 ms. Each test consisted of 60 completely randomized pairs (5 ITIs x 3 OCs x 4 repetitions). Each S underwent 6 tests differing in the factors "step", i.e. ITI(A)-ITI(B) (5 ms and 10 ms) and ISI between the sequences of a pair (0.5, 1.0, 1.5 s). The interval between two successive pairs was fixed to 3 s. The tests were presented in different orders to each S so that each possible order of tests was presented once (3 ISIs x 2 steps = 6 tests). Each test was presented twice to yield 8 repetitions per S and combination of factors.

**Table 1**
The Four-Factorial Design

F1: ITI = 5, 10, 15, 20, 25 ms

F2: Step 1 (5ms) Step 2 (10ms)

F3:

| | | | | | |
|---|---|---|---|---|---|
| OC1 | ITI | :ITI+5 | OC1 | ITI | :ITI+10 |
| OC2 | ITI+5 | : ITI | OC2 | ITI+10 | : ITI |
| OC3 | ITI | : ITI | OC3 | ITI | : ITI |

F4: ISI = 0.5, 1.0, 1.5 s

ITI: Inter-tap interval
Step: ITI1-ITI2
OC: Ordering condition
ISI: Inter-stimulus interval

## RESULTS AND DISCUSSION

For each S the 8 repetitions were pooled to yield an interval-scaled dependent variable. Fig. 1 shows the data for the three ordering conditions separately for both steps, but pooled over ISIs. Data did not depart from normal distribution or from homogeneity of variance (BartlettBox-Test: F(89, 2007) = 1.05752, p = 0.335). A four-factorial univariate analysis of variance (ITI, Step, OC, ISI) (SPSS [4]) showed significant main effects for all factors for ISI on the 5%-level, for all other factors on the 1%-level. There was no third or higher degree interaction, but Step x OC and OC x ITI interactions were highly significant. On the 5%-level the step x ITI interaction is significant, too (Tab. 2). The significant main effects of step, OC and ITI confirm the results of our previous investigations (Tillmann/Piroth 1986) [10] In varying ISI between the stimuli to be compared we included a new factor in the investigation that is important for the discussion of the order effect. In Tillmann/Piroth 1986 [10] we supposed that the order effect might be explained in terms of the classical "time order error" (TOE) in duration discrimi-

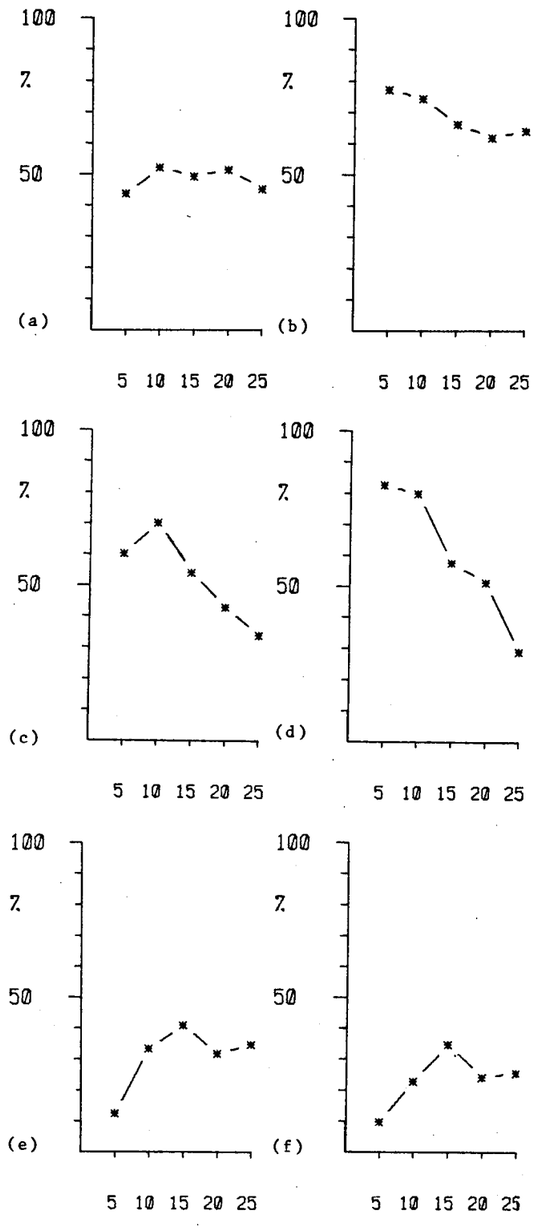


Fig. 1: Percent 'Different'-Responses

(a) 1-step, OC1 (b) 2-step, OC1
(c) 1-step, OC2 (d) 2-step, OC2
(e) 1-step, OC3 (e) 2-step, OC3

**Table 2**
Main Effects and Interactions

Main Effects:

| | | | |
|---|---|---|---|
| F1: | ITI | F(4,450) = 12.06453 | p<0.01 ** |
| F2: | Step | F(1,450) = 18.16458 | p<0.01 ** |
| F3: | OC | F(2,450) =153.10276 | p<0.01 ** |
| F4: | ISI | F(2,450) = 3.65926 | p<0.05 * |

Interactions:

| | | |
|---|---|---|
| F1 x F2: | F(4,450) = 2.95247 | p<0.05 * |
| F1 x F3: | F(8,450) = 15.22227 | p<0.01 ** |
| F2 x F3: | F(2,450) = 23.82372 | p<0.01 ** |

Caption as in Tab. 1

nation (Stott 1935) [9]. Since the overall duration D of each sequence covaries with ITI (D = 9 x 5.2 ms + 8 x ITI) we may hypothesize that the Ss' judgments in the 2IAX-test are at least partially based on durational differences between the sequences of a pair or ITI differences. According to Allan/Kristofferson 1974 [1] there is another effect that is special in duration discrimination besides TOE: discriminability of durations is not influenced by variation of ISI between the pairs to be compared.
Now, if duration discrimination is an important factor in the Ss' judgments in the present experiment, we should expect that discriminability is unaffected or only slightly influenced by variations of ISI and that the order effect does not interact with ISI. This is the case, since the main effect of ISI is significant only on the 5%-level and since there are no interactions that include the factor ISI (Tab. 2). The main effect of ISI is based on a special contrast between the smallest (0.5 s) and the largest value of ISI (1.5 s) only (ISI1 and ISI3: $F(1,450)=7.01085$, $p < 0.01$). So TOE seems to be at least one 'factor constituting the order effect.
Further information is provided by the analysis of the simple effects within the significant main effects: Step is only a significant factor within ITI = 5 ms and ITI = 10 ms ($F(1,450) = 23.13967$, $p < 0.01$ and $F(1,450) = 4.02881$, $p < 0.05$). In these cases ITI is in the range of the threshold for coincidence of successive stimuli: Since an ITI of 5 ms and an ITI of 10 ms are both below the threshold it is more likely that sequences in 2-step pairs belong to different categories ("continous movement" and "discrete taps"). This interpretation is confirmed by an analysis of the special contrasts: only the contrast ITI = 5 ms vs. ITI = 10 ms is not significant (ITI1 and ITI2: $F(1,450) = 0.05887$, $p = 0.808$; ITI2 and ITI3: $F(1,450) = 27.68914$, $p < 0.01$; ITI3 and ITI4: $F(1,450) = 16.42786$, $p < 0.01$; ITI4 and ITI5: $F(1,450) = 4.08225$, $p < 0.05$).
Step is highly significant only in OC1 and OC2 (OC1 : $F(1,450) = 51.73833$, $p < 0.01$; OC2 : $F(1,450) = 7.53802$, $p < 0.01$). OC3 consisted of pairs of physically equal sequences. Nevertheless, step is significant on the 5%-level in OC3, too ($F(1,450) = 6.53567$, $p < 0.05$). This fact seems to reveal a contextual effect in discriminability: the sameness-criterion used by the Ss' (Pollack/Pisoni 1971 [8]) seems to depend partially on the overall inventory of sequences presented during the test run. OC is highly significant for both steps and all ITIs, but ITI is significant only in OC2 and OC3 (OC2 : $F(4,450) = 31.75895$, $p < 0.01$; OC3: $F(4,450) = 9.54535$, $p < 0.01$). This can be explained by concidering the form of the discrimination curves: in OC2, discriminability decays with increasing ITI, so that a significant effect arises, in OC1 discriminability is bad and remaines nearly constant along the ITI-continuum. In OC3 the effect is due to a significant variation of different'-answers along the continuum that yields a peak when ITI is 15 ms.
The analysis of the special contrasts within the order effect shows that there is a significant difference between OC1 and OC2 as well as between OC1 and OC3 (OC1 and OC2: $F(1,450) = 60.04474$, $p < 0.01$; OC1 and OC3: $F(1,450) = 245.16078$, $p < 0.01$). Now, an order effect in the discriminability of stimuli in a 2IAX-discrimination test can arise if perceptual equality of the pairs departs from physical equality. Tillmann/Piroth 1986 [10] argue that in pairs of sequences of the kind used in the present investigation the second sequence has to be longer than the first to be sensed as being 'same'. From another point of view, 'this means that the physically equal sequences of the AA-pairs in OC3 are not perceptually equal. Additionally, the sequence with ITI = 15 ms is in the range of the threshold for coincidence of successive stimuli. According to the theory of categorical perception, discriminability increases near category bounderies (e.g. Liberman et al. 1967 [3]). Since 'continuous movement' and discrete taps' are established categories in natural cases of tactile perception, we can suggest that there is a peak in discriminability, if two stimuli of different categories are presented in a pair. According to our assumption on perceptual equality the second sequence of an AA-pair consisting of two sequences with ITI = 15 ms will be sensed to be faster than the first. Since ITI = 5 ms and ITI = 10 ms are clearly below the coincidence threshold, the first sequence of the 15ms:15ms-pair is possibly sensed to be above and the second to be below this threshold. This may explain the peak in discriminability found for physically equal pairs of sequences with ITI = 15 ms.
The discussion of order effects is not uncommon throughout literature on normal speech perception, too (e.g. Ohde/Sharf 1977 [5], Uselding 1977 [11]).
Even the order effect in duration discrimination (TOE) may be found in speech data. Thus, Lehiste 1973 [2] introduced the notion of 'final lengthening' to describe the phenomenon that in syllable sequences syllable duration increases at the end of the sequence. Now, our presentation of tap sequences in 2IAX-pairs (which are at least minimal sequences of two stimuli) caused the effect that the second member of the sequences had to be longer to be perceived as being as long as the first. As mentioned, it was possible to reproduce with acoustic stimuli. So, one might suppose that a similar effect concerning the perception of syllable duration is compensated by 'final lengthening': since the last syllables are physically longer in duration they might be sensed as being as long as the proceeding ones.

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