

# Electrical stimulation of mechanoreceptors

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**Abstract.** Within the field of Rehabilitation Engineering, this work is aimed at identifying the optimal parameters of electric current stimulus which activate the nervous axons of mechanoreceptors found in the fingertip, allowing, this way, to resemble tactile senses. These sensorial feelings can be used by aiding technological means, namely, the sensorial substitution technology, in an attempt to render information to blind people through the tactile sense. The physical pressure on sensorial areas (fingertips) used for reading activities through the Braille System is the main effect that is imitated and studied in this research work. An experimental aiding prototype for Braille reading research has been developed and tested with blinds and reduced vision people, with highly satisfactory results.

## 1. Introduction

Assisting Technology (AT), when applied correctly, helps to overcome the limitations set by impairing conditions. Its core objective is to ease the execution of a task performed by an impaired person, within a given context for such an activity [1-2]. In the field of assistance to blind and visually impaired persons, whenever vision augmentation devices are not proper enough, the specialist resorts to using AT devices based on sensorial substitution [3]. This approach consists on capturing information that is generally perceived by normal vision and sending it to the user via another sense, typically the tactile or the hearing senses.

The devices used for sensorial substitution require three basic components: an interface that captures information of variables from the surrounding environment, a data processing system and, finally, an element that renders adequately the useful information to the user.

In order to capture and send the context information to the user, several tactile stimulation devices have been developed, the so called tactile displays, which operate by stimulating the perceptive nervous receptors of the skin. Several actuator types have been devised to stimulate the tactile sense. According to the research published in [4], there are three categories according to stimulus type: thermal, electrical and mechanical. Thermal actuators are heat pumps that stimulate the skin receptors that are sensitive to temperature changes. Electrical actuators are electrodes charged by an electrical variable (volts/amps) and which objective is to activate not the receptors but the associated afferent nerve terminals. Finally, the mechanical actuators translate the information into a force, a displacement and/or vibration that can be detected by the mechanoreceptors of the skin.

The tactile sense displays a series of advantages over auditive stimulation [3]. Moreover the electrical stimulation offers some advantages over the other approaches: it lacks thermal inertia, mechanical fatigue or wear of mobile elements, besides permitting manufacture compact designs with solid state component, all in a low-cost small-size package.

Main problems that visually impaired persons have to face are: to have access to reading material, to be restricted as regards mobility and orientation, and to manipulate and recognize objects.

As regards reading, the Braille reading/writing system is widely used by blinds and deaf/blind persons, for its universality and relatively easy usage. On this direction, this work presents a contribution to the selection of current stimulation parameters, in order to obtain a reliable tactile sensitivity in blinds so as to let them read in Braille via an adequately designed interface.

### 1.1. Human skin structure

Various mechanoreceptors of the fleshy fingertip were studied, mainly: (1) the Meissner corpuscle of rapidly adapting (RA) mechanoreceptors; (2) the Merkel cells, or slowly adapting type I (SAI) mechanoreceptors; (3) the Ruffini terminal, or slowly adapting type II (SAII) mechanoreceptors and, (4) the Pacinian corpuscles (PC). The number of SAI receptors is very small; hence, they were excluded from the study. Previous research works [5-8] have considered that it was possible to stimulate the mechanoreceptors separately and that the combination of these stimuli could produce different tactile sensitivity (responses). Figure 1 shows a cross section of human skin. It is assumed that RA and PC can perceive vibration, whereas SAI senses pressure [7-8]. Sometimes RA and PC (fastly adapting mechanoreceptors) are considered speed and acceleration sensors because they respond to strain with just one impulse, whereas SAI (slowly adapting mechanoreceptor) is called the position, or displacement, sensor because it responds to the intensity and duration of the stimulus.

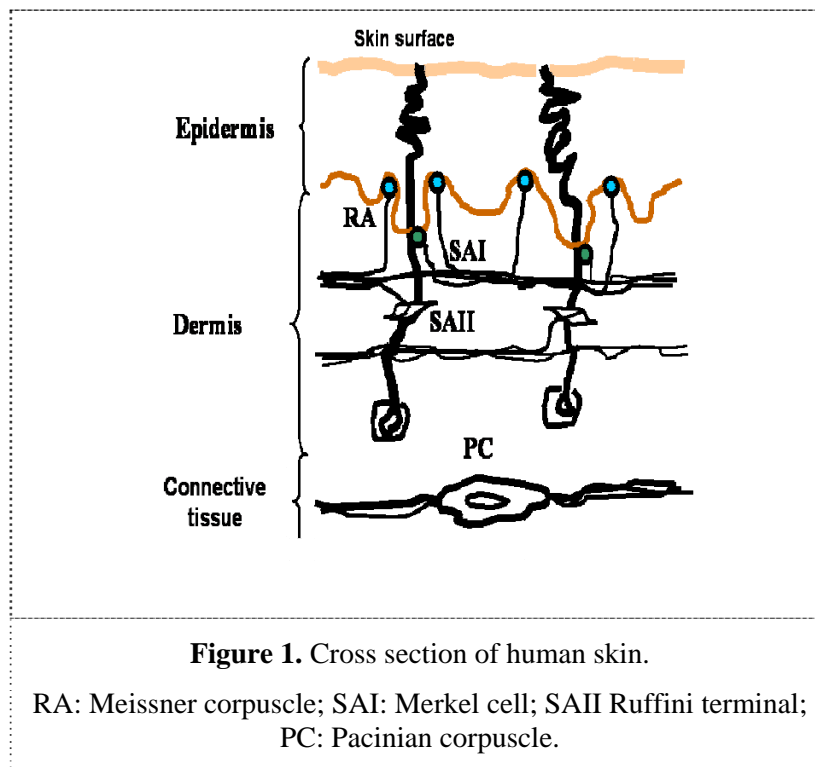


Table 1[7] shows the main features of mechanoreceptors that are taken into account at the time of stimulation.

As a result of nerve size difference, the electrical stimulus of mechanoreceptor nerves is much easier to do than that of afferent nerves because, in general, the stimulation threshold increases with diameter size [7].

Another important characteristic of the fingertip is the thickness of the corneous layer of the skin, of approximately 600  $\mu\text{m}$ , whereas in other body skin parts, it may be as thin as 15  $\mu\text{m}$  [7-8].

**Table 1.** Depth, diameter and orientation of mechanoreceptor axons respecting the fleshy surface of the fingertip.

Mechanoreceptors	Depth	Diameter	Orientation
Meissner(RA)	0.7 mm	3 ~ 5 $\mu\text{m}$	Perpendicular
Merkel(SAI)	0.9 mm	7 ~ 12 $\mu\text{m}$	Parallel
Pacinian(PC)	2,0 cm	5 ~ 13 $\mu\text{m}$	Parallel
Pain, heat and cold	2.5 cm	1 ~ $\mu\text{m}$	-----

### 1.2. Mechanism of selective electrical stimulation

Research papers on electrical stimulation mechanisms were reviewed, especially those where distribution control was performed of an electrical current source acting on the skin surface, and the indirect activation of nerves [7-8]. From these works, it is known that when the pulse of cathode (negative) current is applied to the skin surface, the axons of nerves oriented horizontally to the skin surface are activated. Conversely, when anode (positive) current is applied, the nerves oriented vertically to the skin surface are activated, such as the RA axon.

## 2. Development of the proposed prototype

In order to achieve a pressure feeling, a stimulus signal is defined as in Figure 2, where some restrictions are added in order to avoid possible lesions to the cutaneous tissue. First, the maximum output current of an electrode is limited to 2mA. Besides, even though the stimulation can be either anodic or cathodic, the typical applied current is two-phase (negative and positive) so as to be able to eliminate the accumulation of charges on the skin surface.

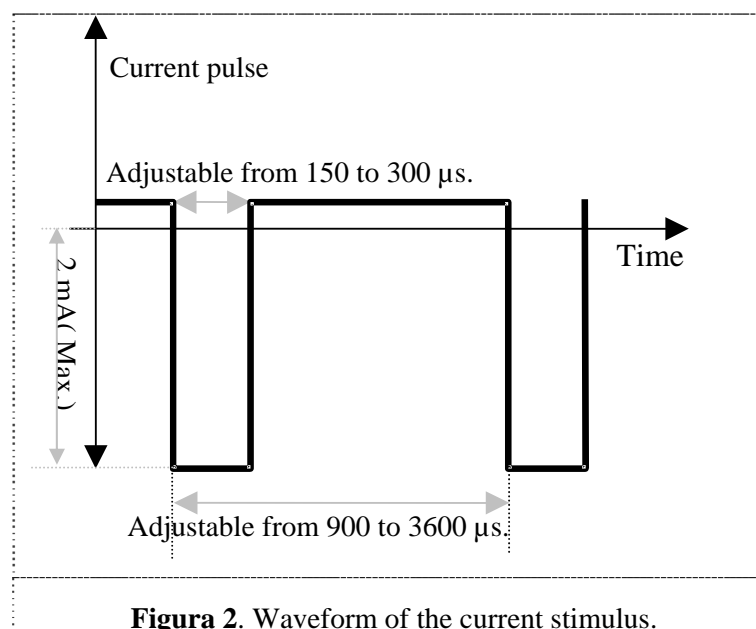
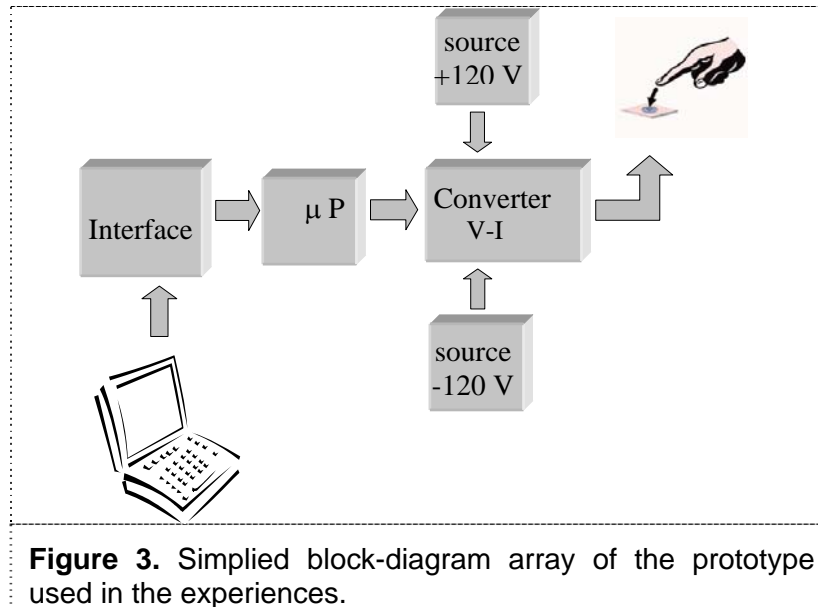


Figure 3 shows a simplified block-diagram array of the prototype used in the experiences.

The electrocutaneous stimulus is controlled via a PC. A software developed for this work allows setting the parameters linked to the stimulation pulse (pulse frequency and pulse width). The selection of pulse width is made at 10  $\mu\text{s}$  steps, in the 150-300  $\mu\text{s}$  range.

When choosing the pulse width, it becomes readily available to the user a frequency selection set of three different values (F1, F2, and F3) ranging from 278 to 1111 Hz, as shown in Table 2. For each frequency value (F1, F2 and F3), a ratio  $A_p/T$  is kept constant, where  $A_p$  is the active pulse width and  $T$  is the period of the signal.

The interface (CP2102) allows adapting the PC's output information via USB to UART.



**Table 2.** Frequency and Pulse-Width values permitted by prototype

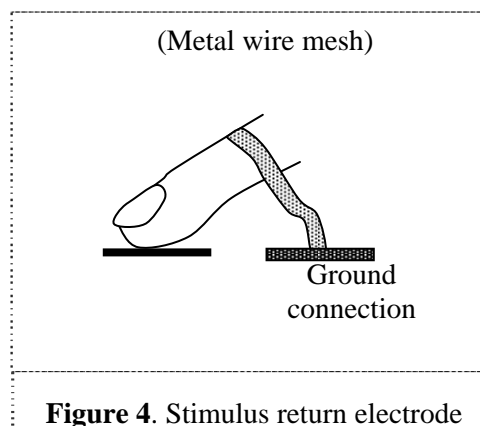
Pulse width [μs]	Frequency [Hz]		
	F1	F2	F3
	for a ratio $A_p/T=0,16$	for a ratio $A_p/T=0,12$	for a ratio $A_p/T=0,08$
150	1111	714	555
160	1042	685	521
170	980	658	490
180	926	633	463
190	877	610	439
200	833	588	417
210	794	568	397
220	758	549	379
230	725	532	362
240	695	515	347
250	666	500	333
260	641	485	320
270	617	472	309
280	595	459	298
290	575	446	287
300	555	435	278

The microcontroller (MC68HC908QY4) is programmed to receive the chosen parameters and to control the voltage-into-current converter (V-I converter). This last device was built with two current sources, Cascode type, with bipolar transistors adjusted for a maximum output current of 2mA in the negative phase and 0.5mA output in the positive phase of the signal.

The V-I converter is powered by  $\pm 120$  V dc linear sources, with folded V-I characteristic and maximum output current limited to 2mA. These sources also present an isolation transformer.

The stimulation electrode was manufactured according to the knowledge gained in experiences made by this researchers team in previous projects [9-11], while altogether meeting the requirements of small size, simplicity and low cost for the device. This electrode is a 0.1cm dia. steel pin inserted in a polished acrylic pad.

The electrode for stimuli feedback was manufactured with a metal plate attached to a mesh fastening around the finger (Figure 4).



### 3. Experiences

#### 3.1. Methodology

The experiences were oriented to use cathodic stimulation in order to mimic the tactile sensitivity (TS) by means of activating the various mechanoreceptors. To this aim, the following factors were evaluated:

- Sensitivity to perceive the first TS, with current intensity.
- Changes in TS perceived, with increases in current intensity.
- Range of the Ap/T ratio and active pulse width of the electric stimulus that is related to each TS.

A comparative experience was carried out with two groups of adult persons, so as to analyze the sensitivity while perceiving the TS with current intensity. The first group consisted of 10 normal-vision persons and the second group had 7 visually impaired persons.

The experience also tested the changes in sensitivity as regards current intensity value. This was specifically experienced for a 200Hz frequency and 200  $\mu$ s pulse width in a visually impaired person and 3 blind ones.

Upon these experiences, tests were made to discern the variability range of the stimulus parameters (Ap/T ratio and pulse width), with two groups; the first one included four normal-vision adults while the second group had eight visually impaired and blind adults. The main objective of the experience with the first group is to study the stimulation mechanisms so as to reduce the number of parameters to include in the experiences of the second group.

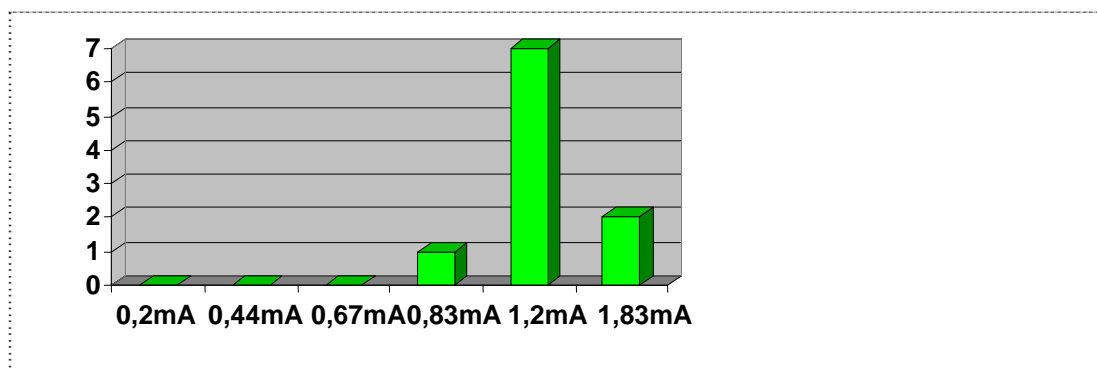
The procedure of the tests consisted in stimulating at first with the least current intensity possible, and increasing it until reaching the first TS by the person. It was recorded only the data where TS was

obtained, up to the current threshold acceptable for each individual, without coming into annoying sensation. The TS perceived were: Vibration, Pressure, Pricking, and Tickling.

- Vibration (Vi): sensation of intermittent tact.
- Pressure (P): sensation of permanent tact.
- Pricking (Pr): sensation of acute pressure, resembling that one caused by a pin.
- Tickling (T): sensation of smooth tact or high-frequency vibration.

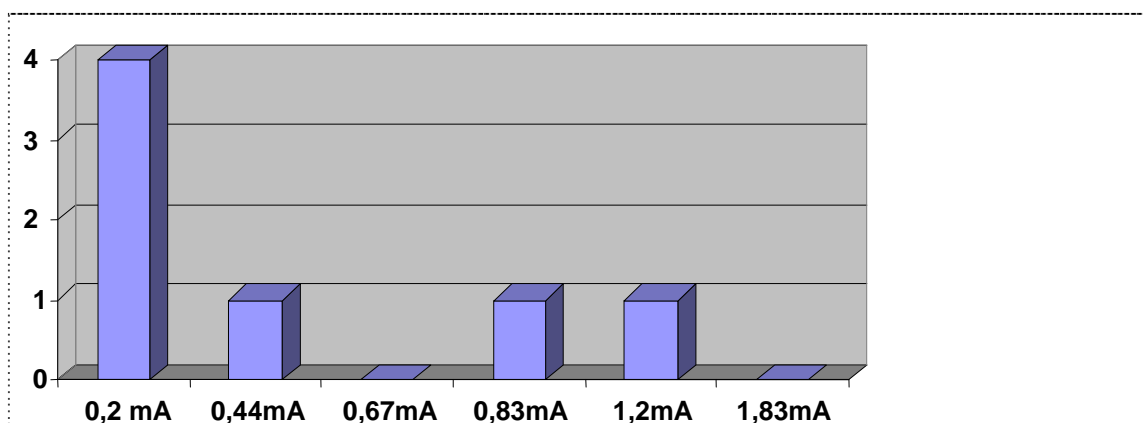
### 3.2. Results.

Figure 5 shows the experience results on sensitivity of normal vision persons to the perception of the first TS with current intensity. It is clearly noted an activation threshold of about 1.2mA.



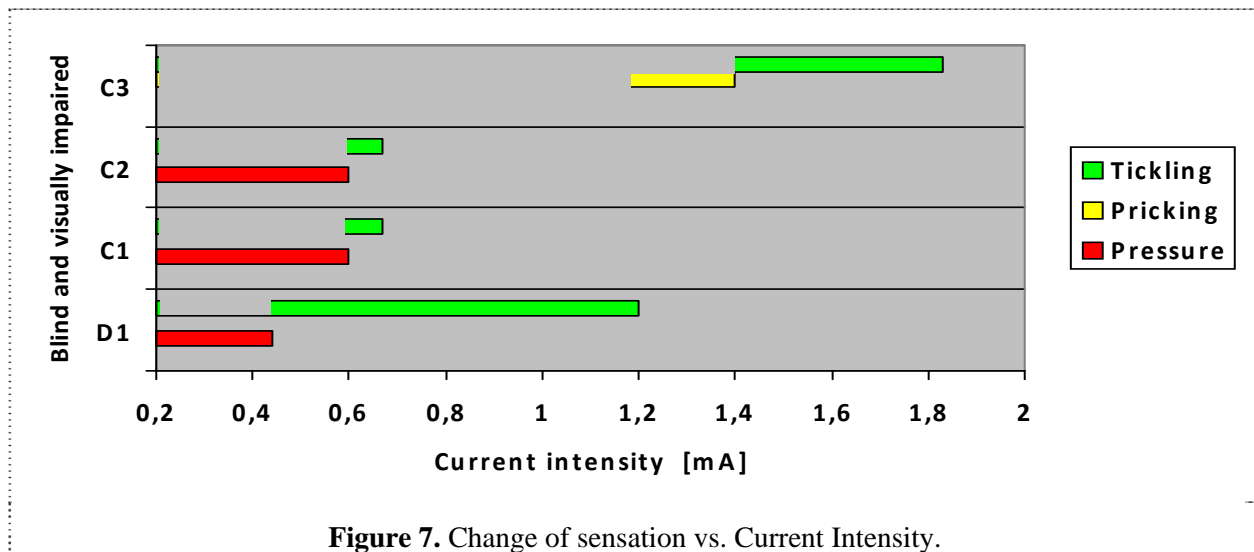
**Figure 5.** Number of normal-vision persons that perceive the initial tactile sensation vs. current intensity.

Figure 6 displays the results obtained for activation current thresholds for blind and visually impaired persons. Stimuli are perceived by most users from as early as 0.2mA. This value shows the high tactile sensitivity that blinds and visually impaired persons have, with very low current intensity thresholds. Due to this fact, moistening of fingertips was required by very few persons.



**Figure 6.** Number of blind and visually impaired persons that perceive the initial TS vs. Current intensity.

It is worth mentioning that in the group of blind and visually impaired persons, two persons presented high impedance in their fingertips due to the kind of daily manual work they do. This fact increases the activation threshold.



In Figure 7, it can be noted a change in TS perceived when the current intensity threshold is increased, that ranges from a pressure or pricking feeling (detected by the Merkel cells) to a tickling feeling. This can be explained by the fact that when the current intensity is increased, the mechanoreceptors lying deeper, as the Pacini corpuscles, can be activated as well, thus arising a tickling sensation.

**Table 3.** Number of normal-vision persons who perceive different TS, according to Ap/T ratio and Active Width Pulse.

ST	Ap/T	Active Pulse Width from 150 to 300 $\mu$ s, with 10 $\mu$ s steps															
		220								230							
		0,08	0,12	0,16	0,20	0,24	0,28	0,32	0,36	0,40	0,44	0,48	0,52	0,56	0,60	0,64	0,68
T	0,08	4	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0
	0,12	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0,16	4	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0
Vi	0,08	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0	0
	0,12	0	0	4	4	4	2	2	0	0	0	0	0	0	0	0	0
	0,16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P	0,08	0	0	0	0	0	0	4	4	4	4	4	4	1	1	0	0
	0,12	0	0	0	0	0	2	2	4	4	4	4	4	3	3	3	3
	0,16	0	0	0	0	4	4	4	4	4	2	0	0	0	2	2	0
Pr	0,08	0	0	0	0	0	0	0	0	0	0	0	0	3	3	4	4
	0,12	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
	0,16	0	0	0	0	0	0	0	0	0	2	4	4	4	2	2	4

As regards the identification of the variability range of stimulus parameters, the experience results with the first group (Table 3) allowed to denote that the TSs for Vi and T are perceived with active pulse widths smaller than 200 $\mu$ s, with 0.08 and 0.12 Ap/T ratios. The TS of P can be perceived

isolately from the remaining TSs, with pulse widths of 220 and 230 $\mu$ s, with the three Ap/T ratios. For this reason, to continue the experiences with the blind and visually impaired persons, the following pulse widths were chosen: 200, 250 and 300 $\mu$ s, and the three values of Ap/T ratios. The data of the experience performed with this group are detailed in Table 4.

**Table 4.** Number of blind and visually impaired persons that perceive the various TSs according to the Ap/T ratio and active pulse width.

ST	Ap/T	Pulse Width [ $\mu$ s]		
		200	250	300
T	0,08	0	0	0
	0,12	5	6	0
	0,16	0	0	0
Vi	0,08	0	0	0
	0,12	2	0	0
	0,16	0	0	0
P	0,08	8	8	2
	0,12	0	1	8
	0,16	8	8	2
Pr	0,08	0	0	6
	0,12	1	1	0
	0,16	0	0	6

#### 4. Conclusions.

In the series of experiences performed with blind and visually impaired persons, it was possible to reach the perception of “virtual” TS starting from very low current thresholds (0,2mA), because of the high level of tactile sensitivity of these persons. This threshold, however, depends on the impedance of the fleshy fingertip of the individual under test, in strong relationship with the type of manual work performed by person.

It was noted a change in the resembled tactile sensitivity as there was a gradual increase in current intensity, which proved the theoretical base described in references.

The adequate stimulus to have a clear and well-defined pressure sensation is attained with Ap/T ratios of 0.08 and 0.16 and active pulse widths of 200 y 250 $\mu$ s.

#### 5. References

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