



The spatial characteristics of the painful thermal grill illusion [☆]

Ruth Defrin ^{a,*}, Anat Benstein-Sheraizin ^a, Adva Bezalel ^a, Ofira Mantzur ^a,
Lars Arendt-Nielsen ^b

^a Department of Physical Therapy, Sackler Faculty of Medicine, Tel-Aviv University, Tel-Aviv, Israel

^b Center for Motor-Sensory Integration, Aalborg University, Aalborg, Denmark

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Abstract

Interlaced cold and warm stimuli may induce a paradoxical burning sensation termed the “thermal grill illusion”. Studies on the grill illusion have yielded contradictory results regarding its quality and intensity, which in turn led to controversies concerning the underlying mechanism. Some controversies may result from testing the illusion with absolute temperatures thereby disregarding inter-subjects’ variation in temperature sensitivity. Therefore, our aim was to measure the individual threshold of the painful grill illusion (PGI). Another aim was to measure, here for the first time, the spatial boundaries of the PGI by spatially separating between the cooling and warming stimuli. Subjects (10 males, 15 females) underwent measurements of heat-pain (HPT) and cold-pain thresholds (CPT) with 9 and 18 cm² stimulating probes, on the forearm. Subjects also underwent measurement of pain threshold (PT), with one cooling and one heating probe (9 cm² each) activated simultaneously, and separated by 0–30 cm (distances encompassing one or two dermatomes). Simultaneous cold and warm stimuli produced burning pain at all separation distances. PT (~26 and 38 °C) was significantly lower than CPT and HPT, respectively, and was relatively fixed across all distances except for 30 cm at which PT increased towards CPT and HPT values. Gender did not affect the PGI. In conclusion, innocuous cold and warm stimuli can spatially summate, both within and between dermatomes and evoke a PGI. Possibly, non-nociceptive channels integrate onto 2nd or 3rd order nociceptive neurons which in turn induce a unique painful burning resulting from the blend of cold and warm sensations.

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1. Introduction

It was Thunberg (1896) who first observed that spatially interlaced warm and cold stimuli of approximately 40 °C and 20 °C induce a sensation of (paradoxical) heat [35]; a phenomenon later termed the “thermal grill illusion”.

The underlying mechanism of the “grill illusion” is not understood nor is it agreed that the heat sensation produced by a mixture of innocuous warm and cold

stimuli is painful. Studies vary with regard to the frequency of painful and non-painful paradoxical sensations obtained and one possible reason for the discrepancy is the experimental paradigm. The “classical” combination of 20 and 40 °C [1,2,5] and the combination of 15 and 45 °C [16] produced a non-painful heat sensation, however, 20 and 40 °C induced painful heat elsewhere [7]. Various combinations of cold (31–26 °C) and warm (35–40 °C) stimuli induced non-painful heat in 85% of trials [19]. Other combinations, of 18–24 °C with 36–42 °C induced painful heat in all instances [27]. Bouhassira et al. reported that temperatures below heat-pain (–4 to –10 °C) and above cold-pain (+4 to +10 °C) threshold induced painful sensations in 46% of trials [4].

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* Corresponding author.

E-mail address: rutidef@post.tau.ac.il (R. Defrin).

It is possible that there are two kinds of “thermal grill illusions”: painful and non-painful. The paradigms mentioned above, of introducing subjects with absolute temperatures of various intensities, are not designed to investigate a specific “type” of grill. Since subjects vary with regard to their thermal sensitivity, it is not surprising that different temperatures evoked different sensations among different subjects and studies. Thus, instead of administering absolute temperatures and recording the evoked sensations, a more appropriate paradigm to study the “painful grill illusion” (PGI) is to individually induce PGI in each subject and then record the evoking temperatures. Therefore, our first aim was to measure the individual threshold of the PGI (defined as pain evoked by innocuous warm and cold stimuli administered simultaneously) thereby controlling for inter-subjects variations in thermal sensitivity.

Another aim was to measure the spatial boundaries of the PGI. Previous studies had used devices comprising of alternate warming and cooling bars mounted into a fixed frame. These devices enabled the stimulation of a restricted skin area, namely that the paradoxical sensations evoked, depending on close proximity of the bars. This raises the questions whether the grill illusion can occur even when the warming and cooling bars are far apart. Answering this question may shed light on the yet unknown mechanism of the illusion. For example, if the PGI exists over distances that are beyond that of a single dermatome, one may hypothesize on the order of neurons involved in its production.

Therefore, in the present study a new approach was used to study the PGI and testing was conducted with cooling and warming probes that were spatially separated by 0–30 cm on the longitudinal axis of the arm.

2. Methods

2.1. Subjects

Twenty-five healthy volunteers, 10 males and 15 females (mean age 29 years, range 19–45), participated in this study. Subjects suffering of pain, diseases causing potential neural damage (e.g. diabetes), systemic illnesses, skin lesions of any kind, language problems, hearing or speech disorders and mental disorders were excluded. Informed consent was obtained from all subjects after receiving a full explanation of the goals and protocols of the study. The human rights committee of Tel-Aviv University approved the experiments.

Testing took place in a quiet room. Temperature in the room was maintained at 22 ± 2 °C. The subjects were seated in a comfortable armchair with the arm on a supporting structure. All measurements were conducted on the forearm. All subjects were trained in threshold measurements prior to the experiments. The subjects could observe the probes when attached to the skin, at all times.

2.2. Thermal stimulators

Thermal stimuli were delivered using two Peltier based computerized thermal stimulators (TSA II, Medoc Ltd., Israel), with two 3×3 cm contact probes. The principles of the Peltier stimulator were already described [39,41]. The adaptation (baseline) temperature was set to 32 °C. The two stimulators were synchronized via a communication cable and special software and could be operated either separately or simultaneously. In addition, subjects could terminate the stimulation simultaneously for the two stimulators when both were activated. For all the experiments the rate of temperature rise or fall (for warming or cooling, respectively) was set to 2 °C/s.

2.3. Quantitative testing

The heat-pain threshold (HPT), cold-pain threshold (CPT) and pain threshold of the PGI (PT) were measured with the Method of Limits. For HPT and CPT subject received 4 successive ramps of gradually increasing or decreasing temperatures, respectively, starting from a baseline temperature of 32 °C, at a rate of 2 °C/s every 30 s. The subjects were asked to press a switch when pain sensation was first perceived, thus defining the HPT and CPT, respectively [13,44]. Pressing the switch resulted in automatic recording of the threshold temperature and reset the probe temperature to baseline values. HPT and CPT were computed separately, by averaging the readings of 4 successive stimuli in each session.

For PT measurements (i.e. when both warming and cooling were activated simultaneously) subject received 4 successive ramps of gradually increasing and decreasing temperatures (at each probe separately) starting from a baseline temperature of 32 °C, at a rate of 2 °C/s, every 30 s. The subjects were asked to press a switch when a pain sensation was first perceived, thus defining the PT. The subjects were not informed in advance of the quality of pain they would perceive rather they were asked to report the quality of pain after they pressed the switch.

2.4. Procedure

Two experiments were performed.

In experiment 1 (Fig. 1A) 25 subjects underwent training and then measurements of heat-pain threshold (HPT) and cold-pain threshold (CPT) with a single contact probe (stimulation area of 9 cm²) and with two probes (9 cm² each) adjacent to each other (total stimulation area 18 cm², 0 cm separation). That is, HPT and CPT were measured separately, with 9 and 18 cm² stimulation areas. Immediately after each measurement, subjects were asked to report the quality of pain perceived out of a list of descriptors (cool, cold, cold-pain, warm, hot, heat-pain, burning pain, and pricking-pain).

Then, another measurement of pain threshold (PT) was conducted with two probes adjacent to each other (stimulation area 18 cm², 0 cm separation), however this time one probe was set for cooling and the other probe was set for warming (both from an identical adaptation temperature). The instruction to subjects was to press the switch at the first pain sensation perceived. At that moment the temperatures of the warming and cooling probes were recorded and subjects were

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