Evaluating Perceived Coldness of Non-Contact Cooling by Focused Ultrasound *

Hanaho Motoyama[1],Tao Morisaki[1], Masahiro Fujiwara[2], Yasutoshi Makino[1], and Hiroyuki Shinoda[1]

I. Introduction

When a water mist is injected against an ultrasound focus, the mist is rapidly vaporized and the vaporization conveys a non-contact cooling sensation [4]. The cooling sensation has the potential for tactile reproduction of cold objects; however, the psychological aspect has not been evaluated. Only the physical temperature drop has been evaluated [4].

This study evaluates the perceptual coldness of ultrasound cooling by comparing the coldness of a cooled aluminum plate. By modulating the sound pressure distribution, we also investigate the perceptual coldness when a mechanical tactile stimulus (vibration or pressure) is presented simultaneously with a cooling sensation.

II. Presenting Cooling and Tactile Sensation

This section introduces how to present mechanical stimulus and cooling sensation simultaneously. First, only the cooling sensation is presented when a static focus is presented with mist since radiation force is weak [1]. Modulated ultrasound presents vibration, or pressure sensation together with the cooling sensation. Vibration is presented by modulating the amplitude of the focus. This method is known as Amplitude Modulation (AM). Pressure is presented by moving a focus several millimeters along the skin surface at 5 Hz. This is called Lateral Modulation (LM) [2] [3].

III. Evaluation of Perceived Cold Intensity

The experimental setup consists of two RGB cameras (Intel Real Sense D435), 40 kHz ultrasound phased array with 996 transducers [1], and a mist generator (the same as the previous system). The cameras detect the fingertip position by using a color filter. The phased array presented a focus on the detected position. An aluminum cold plate (AS ONE, SCP-85) was also used to present the standard stimuli.

9 males and 2 females (aged 23 to 29) participated in the experiment. They touched the ultrasound cooling stimulus with their right index fingers, and the cold plate (set to 13 and 18 °C) with their left index fingers. Then, they answered which was cooler. The touch timing was simultaneous and the duration was 5 s. The maximum and 60% amplitude was set for the phased array. They did two trials for every condition. All conditions were counterbalanced.

The results (Fig. 1-C) showed that static focus and LM at 5 Hz with maximum amplitude were cooler than an 18 °C aluminum plate. The answered rate was 73% and 64%, respectively. Also, all stimulus was not cooler than a 13 °C plate since the answered rate was under the chance rate (50%). As an exception, the LM was perceived as cool as the 13 °C plate since the rate was 46 %.

This study showed the possibility of the ultrasound cooling sensation being cooler than an 18 °C aluminum plate. Moreover, the cooling and pressure sensations are shown to be simultaneously presentable, which is applicable to the tactile reproduction of cold objects. We will compare the perceived coldness with the physical temperature drop.

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[1]Graduate School of Frontier Sciences, The University of Tokyo, Kashiwa-shi, Chiba, Japan
motoyama@hapis.k.u-tokyo.ac.jp
[2]Department of Electronics and Communication Technology, Nanzan University, Nagoya, Aichi, Japan

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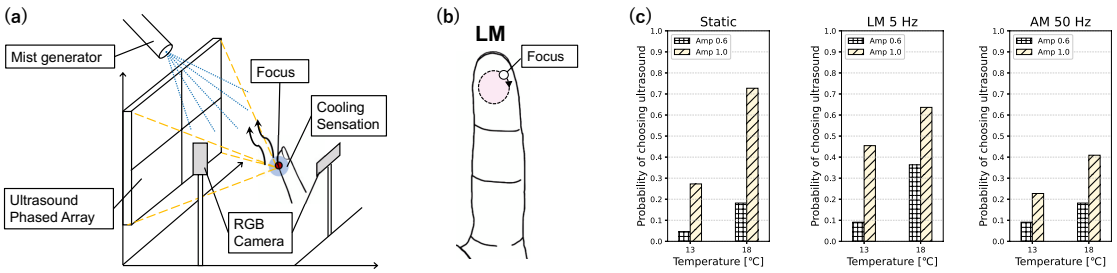

Fig. 1. a) Presentation of cooling sensation to a fingertip. b) Periodic shift of focus in LM. c) The result of the valuation of perceived cold intensity.