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A novel ultrasonic haptic device induces touch sensations with potential applications in neuroscience research

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***Abstract*—Haptic devices can bring a sense of touch to virtual interactions, with substantial benefits for communication and health. Mid-air ultrasound can generate acoustic radiation forces for tailored tactile sensations – 'touch without touching'. To study the neuroscience of haptics, devices must be compatible with neural monitors. In this study, electromagnetic shielding with a Faraday was created. Our device creates a palpable focus of ultrasound with sufficient spatial resolution (5 mm diameter) and radiation pressure (1.56 or 1.76 Pa without or with Faraday cage lid, respectively) to stimulate small areas of skin. Magnetometer measurements showed minimal field strength variability around the system. Therefore, the proposed system could be compatible with neurological monitoring for neuroscience studies.**

***Index Terms*—haptics, acoustic radiation force, touch, neural monitors**

INTRODUCTION

The human need to communicate with touch extends far beyond normal close relationships. Large populations of individuals live in isolation from others due to their occupation, social circumstances, political unrest or health reasons that may limit one's ability to travel. Today, the COVID-19 pandemic has also promoted digitalization of connectivity and increased frequency of remote interactions. Yet the world requires touch communication for virtual interactions to become more like those of natural societal connections. This need remains unmet.

Importantly, a lack of touch has many major health implications. Social isolation is a powerful, but poorly understood risk factor for many illnesses and even for mortality [1]. Socially isolated adults risk elevated blood pressure, untreated infections, cognitive decline and many mental health disorders (reviewed in [2]). In the USA alone, the estimated annual expenditure due to social isolation is 6.7 billion US dollars (American Association of Retired Persons, [3]), with associated costs of isolation being difficult to measure and likely even higher [4].

To build realistic, high-fidelity virtual interactions, mid-air ultrasound can generate acoustic radiation forces that create targeted and bespoke tactile sensations – 'touch without touching'. Ultrasound provides a method to create touch sensations over distance with full spatial (electronic focus

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steering) and temporal (pulse parameters) control of touch patterns. This creates tailored, controllable haptic sensations without any physical instruments touching the skin. Time-averaged acoustic radiation force (ARF) can push the air-skin -interface with either a constant force or in pulsed fashion to achieve palpation-like sensations [5].

Mid-air ultrasound haptic technology has been previously applied to virtual and augmented reality [6], with only air moved by ultrasound [7] to touch the skin. The acoustic impedance difference between air and skin is considerable, thus sound entry to soft tissues is safely negligible. Acoustic isolation methods can ensure that the delicate hearing system is not breached. Therefore, ARF can be considered to provide a safe and controllable touch stimuli. Overall, ultrasonic haptics have huge potential to create realistic virtual contact interactions remotely.

To our knowledge, the potential of ultrasonic haptics to stimulate neural pathways relevant to affective touch have not been investigated before. An ultrasonic haptic system must be compatible with neurological monitoring devices and free from electromagnetic cross-talk to enable subsequent research. For this consideration, we aimed to (i) establish an ultrasonic haptic device with a Faraday cage; (ii) characterize the acoustic field transmitted through the Faraday cage and (iii) quantify the varying magnetic field strengths induced by the ultrasonic haptic system.

METHODS

Acoustic simulations were used to model the acoustic field and aid our haptic device design. Our ultrasonic system (f = 42 kHz) is a dish array of piezoelectric transducer elements (Fig 1A) 1 placed in a Faraday cage. The system is driven by an amplified signal generator (duty cycle = 50 percent, PRF = 130-150 Hz). The array provides a point geometric focus of ultrasound with a 0.5 cm diameter. Based on simulations, an experimental arrangement was established. The custom-made system comprises a bowl construct with elements arranged in circularly with a total of 168 elements. Fig 1A illustrates the final dish array and the shielding of it (Fig 1B) provided by a Faraday cage.

The normalized (time-averaged) sound intensity distribution was measured by a receiver transducer moved orthogonally with a motorized XYZ-translation stage. The acoustic radiation forces generated were also measured by placement against an electronic weighing balance. The reading from the balance was used to determine the time-averaged intensity distribution.

The potential electric field generated or electric radiation emitted by the transducer arrangement is intended to minimize its influence on neural measurements. However, a Faraday cage is not effective in reducing the magnetic field potentially generated by the alternating currents in the transducer arrangement. Therefore, magnetic field strength induced by the ultrasound system was characterized using a magnetometer from the side and from above at different distances from 12 cm to 2 metres from the system. The magnetometer allowed us to quantify the magnetic field in comparison to ambient magnetic field at frequencies relevant to central nervous system activity i.e. 0.5-100 Hz, and beyond this range up 1000 Hz.

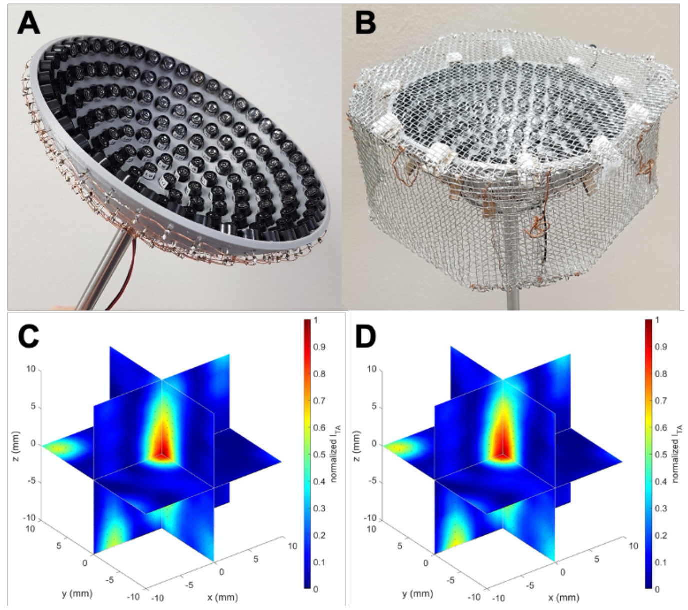

Fig. 1. Our ultrasonic haptic device. A dish-like array carries 168 elements shown in photographs without (A) and with (B) a Faraday cage. Respective graphs illustrate normalized sound intensity distributions in each case (C) and (D) underneath.

RESULTS

Fig 1C shows the normalized intensity distribution in the xy-, xz-, and yz-planes for both without the lid and with the lid of the Faraday cage, when a 1.0 mm step size was used. The Langevin pressure at the focal area was 1.763 Pa (without lid, 1C) and 1.559 Pa (with lid, 1D) when using 80 Vpp and a PRF of 150 Hz.

The magnetic field strength variability with our system was minimal. From the side, at 12 cm, the power spectral density of magnetic field strength levels were pronounced without the Faraday cage lid, as compared to with lid (Fig 2).

At 211 cm, slightly stronger magnetic field, yet negligible, was recorded with lid as compared to without lid. The result suggests that the Faraday cage reduced magnetic field strength levels close to the haptic device. Measuring from the top, at 11 cm, the magnetic field levels were similar with and without the Faraday cage lid (Fig 3). At 174 cm, a slightly stronger magnetic field, yet negligible, was recorded with lid as compared to without lid. The result suggests that the Faraday cage does not affect the magnetic field strength remarkably.

DISCUSSION

We created a haptic stimulation device based on ultrasound with a Faraday cage. The normalized sound intensity distributions highlight the palpable focus of ultrasound with sufficient spatial resolution (5 mm diameter) and acoustic radiation pressure magnitude (1.56-1.76 Pa) to stimulate small areas

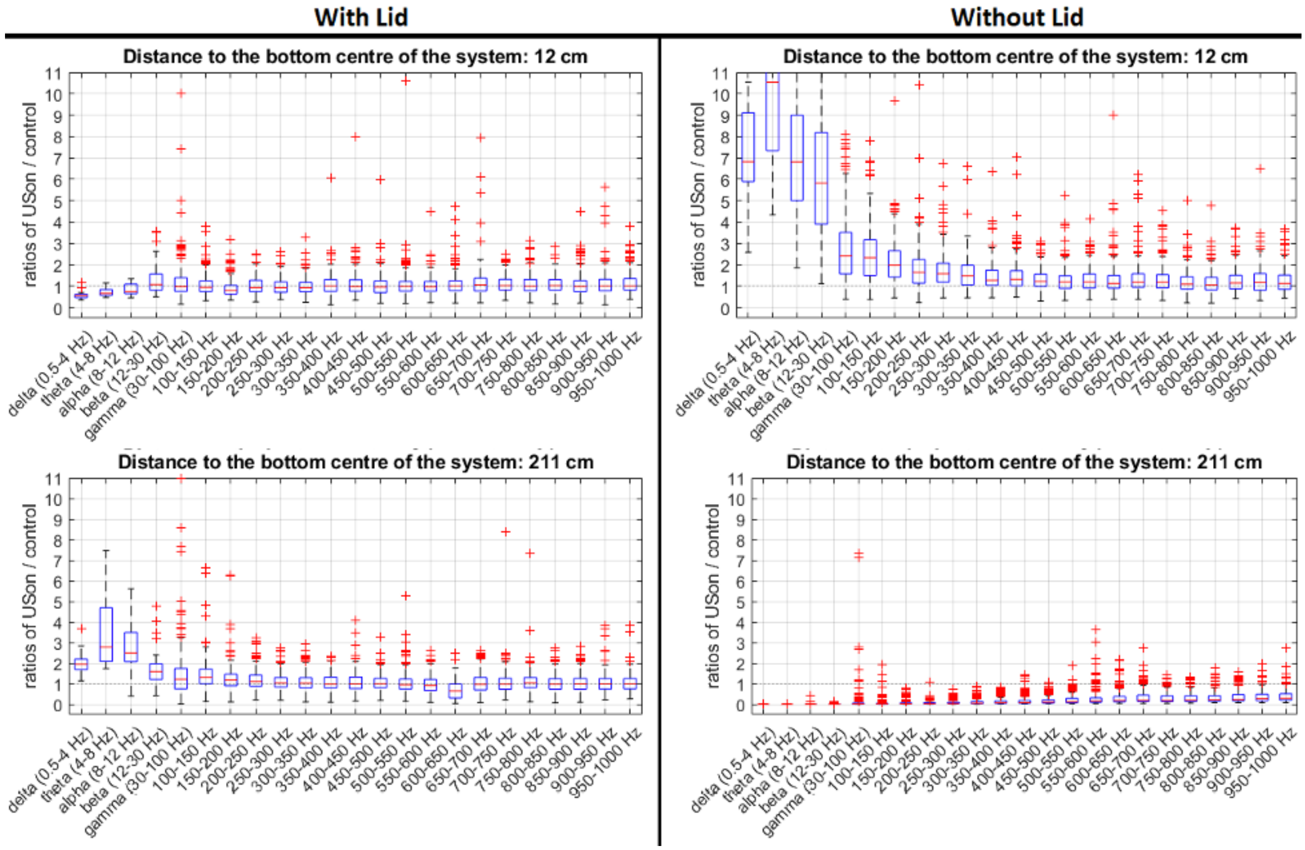

Fig. 2. Graphs of power spectral density ratios for magnetic field strength shown with the magnetometer placed to the side of the system.

of skin. Magnetic shielding with a Faraday cage was accomplished and it did not appear to significantly influence the radiation pressure. Magnetometer measurements showed only minimal field strength fluctuations in the space surrounding the system. These features highlight potential compatibility with neurological monitors, and we have future research plans for neuroscience studies of touch pathways.

Similar haptic devices are becoming commercially available, perhaps most notably from Ultraleap (https://www.ultraleap.com/), which provides non-contact digital interface controls and haptic bio-holograms as teaching tools in mixed reality [8]. Our device provided high enough forces for the purpose of generating haptic sensations through sufficient and localized acoustic radiation force. The Ultraleap researchers report that acoustic radiation force alone may be insufficient for realistic haptic sensations. They suggest further modulation of the carrier waves to create shear waves in the skin (small localized skin vibrations) that are within the perceptible dynamic range for humans (approx. 5-500 Hz) [8].

To conclude, an ultrasonic haptic system with a Faraday cage was achieved without significant disruption to the intensity distribution or size of the focus. Moreover, the magnetic fields generated by the arrangement seem to be relatively small. The results suggest that the proposed system may be suitable for experimentation characterizing neural responses to ultrasonic haptic stimuli.

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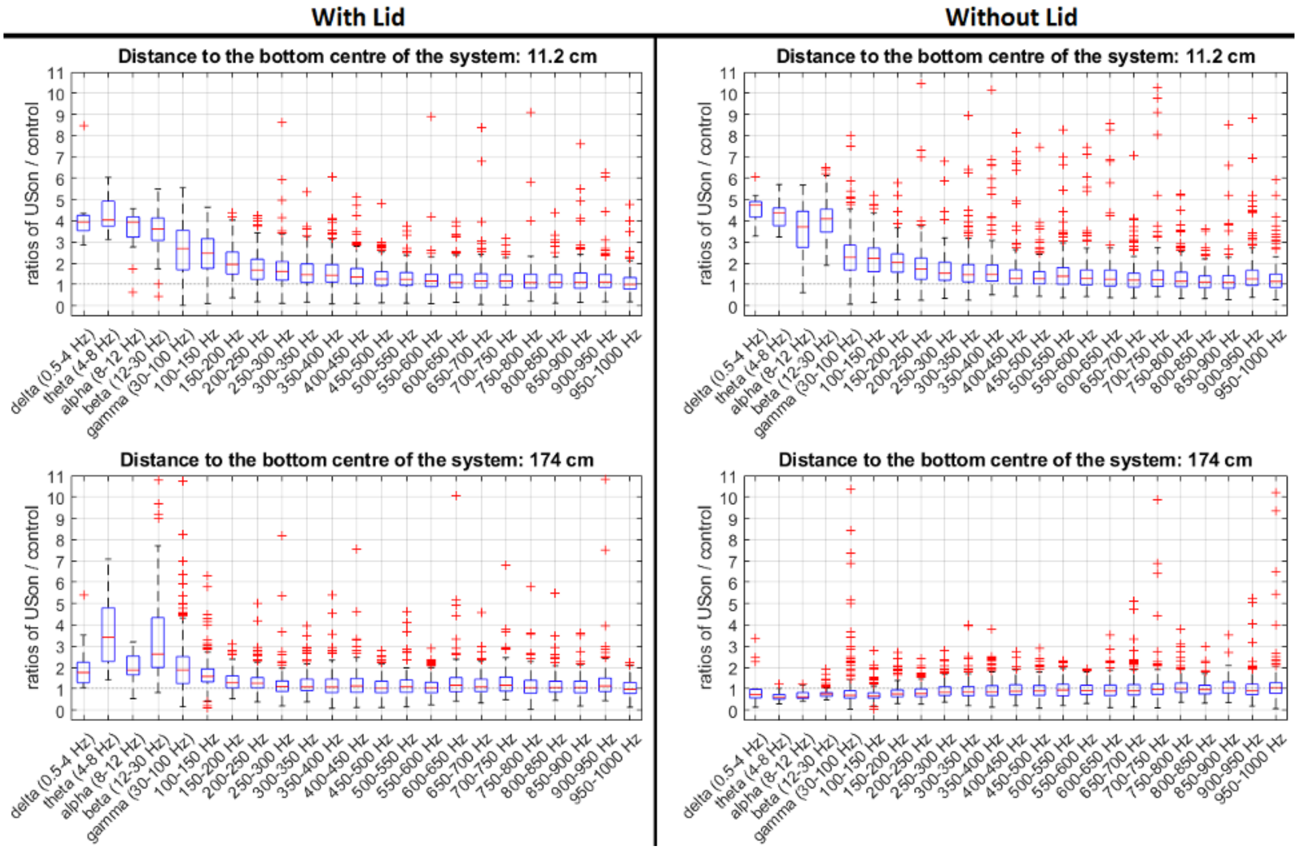

Fig. 3. Graphs of power spectral density ratios for magnetic field strength shown with the magnetometer placed above the system.

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