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Demonstration and validation of a new pressure-based MRI-safe pain tolerance device

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HIGHLIGHTS

- Creation of a novel, MRI-safe, pressure-based pain tolerance device.
- Strong correlation between pain tolerance as assessed by MRI-safe device and as assessed by commercially available algometer (Experiment 1).
- With additional pressure, increased activation in insula, anterior cingulate cortex (Experiment 2).
- Activations found in Experiment 2 were comparable with activations found with other types of pain (e.g., thermal, mechanical).

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ABSTRACT

Background: One of the barriers to studying the behavioral and emotional effects of pain using functional Magnetic Resonance Imaging (fMRI) is the absence of a commercially available, MRI-compatible, pressure-based algometer to elicit pain. The present study sought to address this barrier through creation and validation of a novel MRI-safe apparatus capable of delivering incremental, measurable amounts of pressure inside a scanning bore.
New method: We introduced an MR-safe device used to administer pressure-based pain. To test against a commercially available, MRI-incompatible algometer (AlgoMed), 199 participants reported their pain tolerance for both devices. A second experiment tested the validity of pressure-based pain in an MRI environment by comparing brain activation with established neural networks for pain. 10 participants performed an identical procedure to test for pain tolerance while being scanned in a 7T MRI scanner.
Results: Results support the validity and reliability of our novel device. In Study 1, pain tolerance with this device was strongly correlated with pain tolerance as measured by a commercially available algometer ($r = 0.78$). In Study 2, this device yielded BOLD activation within the insula (BA 13) and anterior cingulate gyrus (BA 24); as pressure increased, activation in these areas parametrically increased.
Comparison with existing method: These findings correspond to other studies using thermal, electrical, or mechanical pain applications. Behavioral and functional data demonstrate that this new device is a valid method of administering pressure-related pain in MRI environments.
Conclusions: Our novel MRI-safe device is a valid instrument to measure and administer pressure-based pain.

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1. Introduction

There is currently no standardized way of administering pressure-based pain in the neuroimaging literature. Using Magnetic Resonance Imaging (MRI), pressure has been administered to the lower back (Gay et al., 2015), foot (Petre et al., 2008), jaw (Shaefer et al., 2001), and thumbnail (Cole et al., 2010). The devices used to administer pressure in these studies are either specifically designed for one piece of anatomy (i.e., the lower back for Gay et al., 2015) or not described in enough detail to replicate for future studies. Additionally, the psychometric properties (i.e., the validity and reliability) of such devices remain under reported. Current methods of administering pressure-based pain in behavioral studies often involve the use of an algometer. Current commercially available algometers cannot be present near an MRI scanner because of their ferrous metal components. This device requires a researcher to actively press downward on the device to create pressure between the device and the participant. This approach would be impractical and sometimes impossible in a scanning environment when the presence of another individual may skew the magnetic field generated by the scanner.

Gay et al. (2015) developed a procedure to administer pressure to participants' lower back while in a supine position. Participants had pain delivered while lying on their backs in an MRI scanner. The researchers found activation in areas previously established in a neural pain network (Tracey, 2005, 2008). While the approach was novel, this device and procedure is primarily useful for scientists interested in back-related pain. Additionally, a device should be created that is flexible in nature, allowing the administration of pain to other parts of the human body. For standard pain tolerance, it may be difficult to generalize Gay et al.'s methods with those currently used with thermal, electrical, or mechanical pain administration.

Pain research extends beyond the realms of psychophysical research and treatment for chronic back pain, jaws, and feet. Psychological constructs relevant to suicide risk, can also be examined with the use of a pain tolerance device. According to the interpersonal-psychological theory of suicide (Joiner, 2005; Van Orden et al., 2010), in order for individuals to be capable of withstanding a lethal suicide attempt, they must have an elevated pain tolerance. Research in suicidality currently uses a standardized approach of measuring and administering pressure-based pain tolerance (e.g., Ribeiro et al., 2014; Witte et al., 2012; Zuromski and Witte, 2015). These studies have typically found a more robust association between measures of pressure pain and relevant outcomes (e.g., fearlessness about death), compared to thermal pain threshold (e.g., Ribeiro et al., 2014). As argued by Ribeiro et al., it is more common for suicide methods to involve pressure (e.g., hanging) than thermal pain. Thus, for this particular area of research to translate into the realms of neuroimaging research, a reproducible method for administering pressure-based pain must be established. If an MRI-safe device that administered pressure were to be psychophysically validated, future research may inquire more about pain, suicidality, and how these two concepts interact.

The goal of the present study was to create an MRI-safe pain tolerance device and validate it on two levels. First, the device would need to reproduce pain tolerance comparable to a widely used, commercially available device. Thus, in Experiment 1, we examine the correlation between pain tolerance as assessed by our MRI-safe device and pain tolerance as assessed by the commercially available alternative. Secondly, the device would need to demonstrate that it elicits brain activation comparable to other pain procedures. This is important to make sure that our custom-made device does not create additional task-related noise otherwise unrelated to pressure or pain. Thus, in Experiment 2 we compare the neural activation elicited with our device with networks reported for thermal, mechanical, and pin-prick pain tolerance.

Fig. 1. Specifications for a custom MRI-safe pain tolerance device.
Device Components:
(1) Two 6 m lengths of vinyl tubing on the end of each will be attached to the BP cuff and the other of which will be attached to the squeeze bulb or pressure gauge. This allows for the experimenter to increase pressure from outside the vicinity of the MRI scanner.
(2) 1 neoprene plastic disc of 3 mm thickness and 58 mm in diameter. The disc was modified from a standard furniture leg coaster. The plastic nub was constructed from a standard 10–32 nylon screw held in place at the center of the plastic disc with a nylon 10–32 hex nut, and an added nylon 10–32 round cap nut.
(3) Masking tape
(4) 1 MABIS adult arm aneroid sphygmomanometer

2. Experiment 1

2.1. Methods

2.1.1. Participants

199 right-handed participants (70% female; 82% Caucasian) with a mean age of 20.6 (SD = 2.16, Range = 19–39) years were recruited from Auburn University in return for extra credit in an undergraduate psychology course. Participants were excluded if they reported being smokers, currently using pain medications, or history of seizures or fainting. All participants were consented according to protocols approved by the university's Institutional Review Board. This experiment took place in a behavioral research laboratory.

2.1.2. Apparatus

2.1.2.1. Device components. The custom MRI-safe pain tolerance device was created with two 6 m lengths of vinyl tubing, 1 neoprene plastic disc commonly used as a furniture leg coaster (58 mm diameter; 3 mm thickness), 1 10-32 nylon screw, 1 nylon 10-32 hex nut, 1 nylon 10-32 round cap nut, and 1 adult arm aneroid sphygmomanometer (MABIS Healthcare). The sphygmomanometer was disassembled and reattached to the vinyl tubing so that the pump and meter of the sphygmomanometer were on one side and the arm cuff on the other. Using a 10-32 hex nut and round cap, one vinyl screw was held in place on the inside of a neoprene plastic disc. See Figs. 1 and 2 for more details.

2.1.2.2. Attaching the device. Fig. 2 depicts the three steps in attaching the MRI-safe pain tolerance device to a participant. Step 1: The neoprene plastic disc was taped to participants' right hand with masking tape so that the nylon cap nut sat comfortably between