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Toward a Better Understanding of Percussive Therapy and Pain

Alex Luscher
Bard College, al9822@bard.edu

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Alex Luscher

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Here, I etch my overwhelming gratitude

to Justin Hulbert, for your unrelenting commitment to helping me blaze past red tape,

challenging my thinking with infinite alternate considerations, and

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to my teammates, for investing in we

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to my family, for always reassuring me that nothing is impossible

forever

"There is addiction to indulgence of sense-pleasures,

which is low, coarse, the way of ordinary people,

unworthy and unprofitable;

and there is addiction to self-mortification,

which is painful, unworthy, and unprofitable.

Avoiding both these extremes,

the Tathagata [The Perfect One]

has realized the Middle Path;

it gives vision, gives knowledge,

and leads to calm, to insight, to enlightenment

and to Nibbana [the end of worldly suffering]"

Buddha, *Dhammacakkappavattana Sutta*

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Abstract

Despite the rapidly-increasing widespread adoption of percussive therapy as a tool for pain management by individual consumers and health professionals alike, relatively little experimental research has been done to clarify the neural mechanisms implicated in the many anecdotal stories of pain reduction. Inspired by an evidence-based theory of pain perception, according to which the brain's anterior cingulate cortex processes both physically and emotionally painful inputs, it was hypothesized that the application of a physical stimulus—percussive therapy—would decrease socially-induced pain more readily than a vibration-removed control. Six conditions spread over three phases of testing were designed to specifically isolate the effect of vibration from other confounds, should such an effect exist. Instead, exploratory analyses revealed that participants in the pain induction conditions who received percussive therapy with or without vibration both reported significantly reduced pain. The mechanisms within percussive therapy beyond vibration that may have contributed to this finding, including touch and other social and cognitive factors, are discussed at length herein.

Keywords: percussive therapy, Theragun, physical pain, social pain, Cyberball

Pain

Pain refers to any discomfort or suffering caused by the biological alarm system. This alarm system is constructed out of a variety of neurological and physiological sensors, relayers, and processors, designed to protect the body from threats. Two categories of pain—physical and social—further classify the type of threat and the resulting painful experience. By definition, these two pain categories are similar in that they are a response to threats, physical or social in nature (Eisenberger, 2012). But decades of debate about which components of these two pain systems are unique and shared remain unresolved. The following subsections will expand this debate through a landscape of their definitions, theories, experimental methodologies, and treatments.

A Brief History of Pain Theory

The overwhelming majority of people, from hunter-gatherers to the modern human, from athletes to office workers, from those suffering from specific diseases to those considered otherwise healthy, will experience some form of pain at some point in their lives. The ubiquity of painful experiences has inspired the deliberation of its mechanisms for millenia. Here, an overview of the major theories that have pushed the study of pain forward aims to contextualize the discussion of modern understandings of pain that will follow. This particular history begins with Plato, the ancient Greek philosopher, as he was one of the first to formalize the theoretical process of defining pain through its mechanisms.

Plato's Intensity Theory posits that pain is an emotion that occurs when sensory inputs exceed a threshold of normality. That is, sensory inputs are summative (Moayedi & Davis, 2013). This model launched the scientific exploration of tactile perception, but fails to account

for differential reactions to the same stimulus and pain that occurs without physical stimulus (Trachsel & Cascella, 2020).

For much of history before and after, many believed that pain was punishment for an immoral act. Renee Descartes directly challenged this idea by detailing a bodily system that was responsible for relaying sensation. Though the medium of communication was animal spirits, which still reflects grounding in religious beliefs. Descartes describes the animal spirit transportation system as a network of hollow tubules that rely on degrees of movement to open gates which control the flow of information. The speed and distance of movement were thought to communicate the intensity and quality of the movement (Moayedi & Davis, 2013). Descartes also posited that this physical system was moderated through the pineal gland, which was described as the mentally-derrived soul of pain (Trachsel & Cascella, 2020). Descartes was a revolutionary in his attempts to explain the physical network of the body and the Dualism between body and mind. Modern observation techniques, however, have shown that many of his hypotheses resemble reality at a high level, but that the fine details fall short. For example, the pineal gland is now thought to contribute most readily to sleep cycles through the production of melatonin, the hollow tubules are actually a diverse network of cells, and the animal spirits are neurotransmitters (Aulinas, 2019; Hyman, 2005).

In 1811, Charles Bell first published a new theory of pain: Specificity Theory. Born out of a realization that the body could discriminate against different types of pain, Bell described a system of infinite sensation neurons which were each tuned to specific sensations with their own pathways to the brain (Moayedi & Davis, 2013). Today, a variety of sensory neurons are thought to be tuned to a small variety of specific sensations. In this way, Bell overestimated the types of

sensory neurons. Additionally, Specificity Theory fails to account for pain that lingers far past the initial stimulus (Trachsel & Cascella, 2020).

Patrick David Wall and Ronald Melzack announced the famous Gate Control Theory of pain in 1965. In this model, pain signal mediation occurs at the level of the spinal cord where the substantia gelatinosa in the dorsal horn acts as the gate. If sensation surpasses a specific threshold, the gate opens, sending a signal through ascending fibers to the brain, where pain is ultimately experienced. If sensation is below a specific threshold, the gate remains closed, and no pain is experienced. This was the first pain theory to acknowledge that this pain threshold could be modulated by descending fibers from the brain that may be influenced by various cognitive or lifestyle factors (Trachsel & Cascella, 2020). Today, this theory is among the most well known theories of pain. It inspired a wide range of studies in the field which have identified a number of oversimplifications in the original model, such as the initial representation of spinal cord architecture and the types of descending fibers (Moayedi & Davis, 2013).

Decades later, Melzack would complicate his Gate Control Theory with another model called the Neuromatrix. In this model, pain is described as a holistic experience derived from nonlinear inputs that originate in the central nervous system rather than the peripheral nervous system, though it can be influenced by signals from the periphery. Each particular pain signal is discriminative, affective-motivational (causes emotional and behavioral adjustments), evaluative-cognitive (involves high level processing) and is given status as a neurosignature. The neurosignature output relies on inputs from sensory receptors, cognitive interpretation, emotional states and traits, neural inhibition, and the endocrine, autonomic, immune, and opioid stress regulation systems (Melzack, 1999). Though social factors are likely to influence the other

systems described in the creation of a neurosignature, social pain is not explicitly described in this model.

The biopsychosocial model of care was first introduced in opposition to the predominant model of biological reductionism used in psychiatry and other forms of western medicine. The holistic consideration of biological, psychological, and sociological factors is by no means a new concept, though Roy Grinker is credited as the first to officially coin this particular term. Of the theories mentioned, the biopsychosocial model appears as the most intuitively comprehensive. It might just be so comprehensive that it fails to achieve the main goal of a model—to be a simplified representation of reality that can be useful for understanding complex processes—as framed by George Box. Due to its breadth, it might instead serve best as a framework for scientists and physicians to begin and continue their search for the causes of a particular phenomenon, such as considering the constellation of inputs that might be contributing to an individual's chronic pain beyond a simple acute causal relationship (Lugg, 2021; Trachsel & Cascella, 2020).

In order to grasp a deeper understanding of the interplay between the constituents of the biopsychosocial model, progress might be most immediately attainable at the level of two categories before scaling to more complex models with many more categories of influence. With this in mind, the current exploration aims to deepen the modern understanding of pain within physical and social dimensions through mechanisms of induction and reduction. Thus, the current understandings of physical pain, social pain, and their interactions are described in detail below.

Physical Pain

Physical pain occurs when sensory and affective signals culminate in an unpleasant experience associated with actual or potential tissue damage (Eisenberger, 2012; Raja et al., 2020). Tissue, in this case, is simply a biological unit of organization one order higher than the cellular level. It refers to any group of similar cells that share structure and function, which exist everywhere in the body (*Tissue*, 2019). The variety of sensors in this pain system, sometimes referred to as nociceptors or afferents, provide individuals with the ability to describe the location, quality, and intensity of a painful stimulus. Taken together, this might culminate in a description of severe throbbing in the right knee. A number of aforementioned formalized theories have attempted to account for the total experience of physical pain, though all so far have encountered practical limitations.

Experimental Models of Physical Pain. In order to expand upon the existing models of pain, researchers must devote themselves to the scientific method so that more precise and generalizable models of pain might be developed. Of course, in order to study pain, study participants must experience pain. For some designs, participants with pre-existing pain, chronic or acute in nature, may be utilized. A major advantage of this design is that participants are experiencing pain as it naturally occurred in their life. This aligns with the ultimate goal of reducing real-life pain. A major disadvantage of this design is that the cause of each participant's pain is uncontrolled, which obscures its source and mechanisms. For other designs, participants may enter the lab without pre-existing pain and may agree to undergo controlled pain induction. This directly overcomes the major problem with naturally-occurring pain in that the source of the pain is highly controlled, but is severely limited in the type and degree of pain ethically permissible.

Because the current study aims to test a novel hypothesis about the specific role of vibration from percussive therapy in the modulation of pain, controlling the source of pain is an important variable that can be accounted for at this early stage in the research process. For this reason, the following section reviews the existing physical pain induction methods.

At its most straightforward level, physical pain is studied through acute experimental stimulation of nociceptors—specialized sensory neurons purposed for the detection of stimuli that might present a threat to the body. Because skin is the largest organ in the body and can easily be accessed exogenously, the majority of physical pain induction is applied to the skin (Reddy et al., 2012). Physical pain stimulation modalities of the skin include mechanical (e.g., touch, pinch, pinprick, pressure), thermal (e.g., hot, cold), electrical, and chemical (e.g., capsaicin, mustard oil). Mechanical stimulation in the form of touch and pressure is unable to target specific receptors and is not generally thought to be painful. For this reason, these modalities are primarily utilized to study allodynia (sensitivity to a stimulus that does not tend to evoke pain). Pinprick primarily activates Aδ fibers—myelinated neurons, 2-5 micrometers (μm) in diameter, that transmit nociceptive signals at the velocity of 5-40 meters per second, which is considered to be fast—but threatens to damage tissue at its nociceptive threshold (Dafny, 2020; Staahl & Drewes, 2004).

Thermal pain through immersion in ice water is often referred to as cold pressor pain because the cold-induced vascular constriction presses on nociceptors, resulting in pain. A variety of pain treatment studies have seen contradictory results with this model. Freeze lesions cause hyperalgesia (increased sensitivity to painful stimuli) for a day through the recruitment of many peripheral mechanisms. Contact heat is applied with a Peltier thermode or heat foil and stimulates first and second pain responses. The initial rapid skin heating stimulates the Aδ fibers.

This is followed by a slower moving signal from C fibers—unmyelinated neurons, 0.4-1.2 μm in diameter, that transmit nociceptive signals at 0.5-2.0 meters per second—described as throbbing, burning, and swelling (Dafny, 2020; Staahl & Drewes, 2004). Contact from this mechanism of heat transfer is a confounding variable that might induce inhibitory effects. Radiant heat procedures avoid this by applying heat through laser pulses to a maximum pricking sensation equivalent to the pinprick so that superficial burns lasting longer than the experimental procedure are avoided. Carbon dioxide lasers are absorbed within the epidermis regardless of skin pigmentation properties. Argon lasers are susceptible to variable reflection. With either laser method, there remains difficulty in standardizing absorption of heat between individuals. Topical chemical stimulation can be achieved with capsaicin or mustard oil. These cause primary and secondary chemical burn reactions that cause an inflammatory response which primarily stimulates C fibers.

A variety of electrical stimulation methods evoke unique sensation patterns. Temporal summation of a fixed stimulation intensity at short fixed intervals causes an increase in sensation over time. This effect is lost with long fixed intervals of fixed stimulation intensities. Spatial summation of fixed intensity at many locations also increases the intensity of the response. Electrical stimulation of any kind directly stimulates the nerve fibers, instead of the receptors. Because different sites on the body have different impedances, clinical generalizations from specific scientific findings should be used in caution.

Endogenous physical pain induction methods include metabolic stress through muscle ischemia and muscular stress through overloading, particularly in the eccentric contraction phase. More invasive physical pain induction methods are rare in humans, but have been used. They include infusions and injections of algesic substances (e.g., hypertonic saline, capsaicin,

bradykinin, serotonin, potassium chloride, glutamate, levo-ascorbic acid, acid phosphate buffer), intra-organ balloon distension, electrical and thermal stimulation, chemical application (glycerol, hypertonic saline, capsaicin) and irritant perfusions (e.g., hypertonic saline, acid) that aim to clarify visceral pain mechanisms. Ethical review boards severely limit the intensity and duration of any invoked pain in humans (Staahl & Drewes, 2004).

Therefore, models of intense and chronic pain are reserved to animal models. Intense irritants (e.g., acidic saline, mustard oil, carrageenan, complete Freund adjuvant, formalin) have been used induce nociceptive pain or inflammatory conditions. Nerve ligations (e.g., L5/L6, sciatic) have been used to induce neuropathic pain. Stress has been used to induce dysfunctional pain. Balloon distension has been used to induce visceral pain. Dietary protocols have been used to induce disease. And viruses (e.g., varicella zoster virus, herpes simplex virus 1) and irradiation have been used to create skin pain.

Since animals are unable to vocalize their pain experience, nociceptive pain is often quantified with spinal reflexes such as the tail flick and paw withdrawal, lifting, flinching, guarding, licking. The effect of irritants is often measured through behavioral observations such as paw lifting, licking, nibbling, biting, shaking, avoiding weight bearing movements, and writhing. Writhing is marked by abdominal contractions and changes in locomotion and movement. Histology and histopathology are also sometimes included in final analyses to confirm that a particular pain induction method resulted in the expected internal changes (Kaliyaperumal et al., 2020).

Because of the evidence for shared mechanisms between physical pain and social pain, social pain induction methods might offer far more ethical ways to induce pain that can be carefully controlled within humans within an experimental setting. Moreover, testing a novel

physical intervention for social pain provides an accessible avenue for insight into the underlying

neural mechanisms that may or may not be involved in the many anecdotal reports of pain

modulation through percussive therapy.

Social Pain

Social pain occurs when interpersonal interactions culminate in an unpleasant experience

that is associated with actual or potential damage to one's sense of social connection or social

value (Eisenberger, 2012; M. Zhang et al., 2019). Unlike the study of physical pain, ostracism,

also referred to as social exclusion, remained largely unexamined scientifically until the 1990s.

Williams, a pioneer in the field of ostracism, is credited with the most comprehensive model of

ostracism to date, among a long list of other accolades within the field. A variety of visual and

verbal cues from others might first signal ostracism—characterized by excluding, ignoring, or

rejection by others. Williams posits that this detection system is an evolutionary response to the

human reliance on social connection for survival. If ostracism is a threat to survival, early

detection is key so that individuals have the opportunity to correct any behaviors that might have

caused others to react undesirably. The detection of this signal manifests as social pain.

What follows social pain are three temporal stages of ostracism: reflexive, reflective, and

resignation. The reflexive pain response describes social pain detection in more detail. It is

triggered by interpretations of threat to four fundamental needs—belonging, self esteem, control,

and meaningful existence. After detection, attentional resources are directed to a reflective state

whereby individuals attempt to evaluate the meaning and importance of the signal in question.

Based on this assessment, coping mechanisms are activated to fortify the needs most under

threat. Chronic exposure to ostracism may deplete the resources required for an individual to

fortify their needs. The result is a state of resignation, whereby more severe feelings of

alienation, depression, helplessness, and unworthiness ensue (Williams, 2009). In this study, the initial reflexive stage of social pain is of primary interest.

Experimental Models of Social Pain.
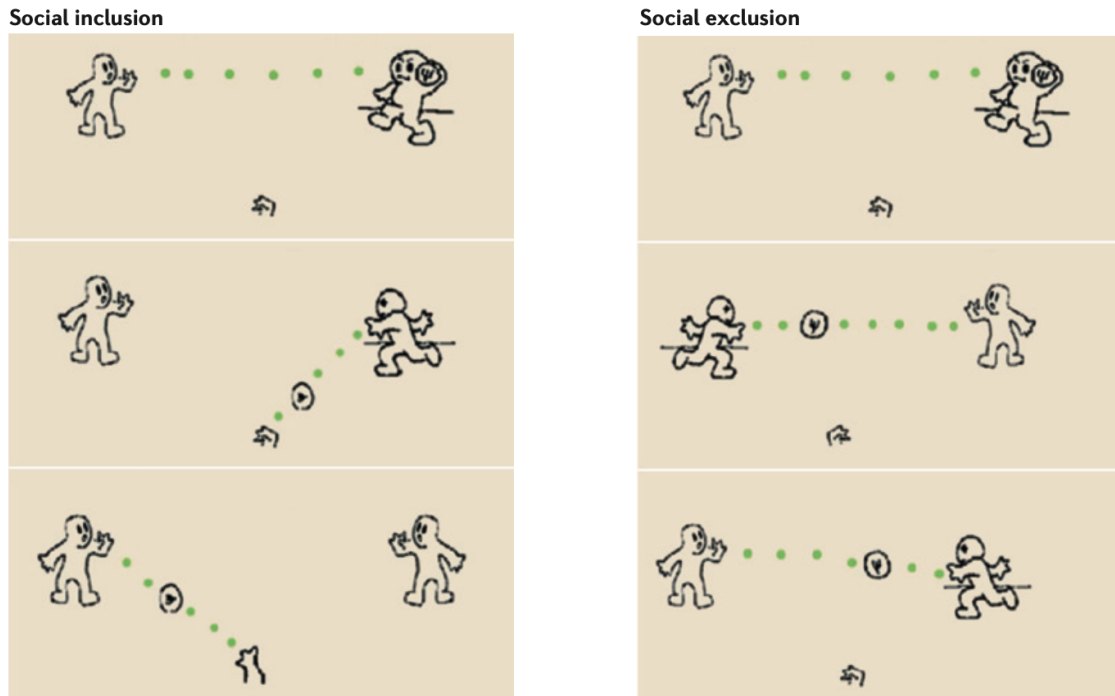
Figure 1. Depiction of Cyberball conditions from Eisenberger (2012).

Since its development, Cyberball has been utilized in hundreds of studies, making it the most popular model for the experimental induction of social pain (Williams, 2018; Williams et al., 2000). In its most common iteration, Cyberball is a virtual ball-tossing game where each human participant plays as the bottom player of the three on screen and is assigned to one of two conditions: social Inclusion and social exclusion (see Figure 1; Eisenberger, 2012). Participants in the Inclusion condition receive the ball an equal number of times throughout the five minutes of gameplay. Participants in the exclusion condition are passed the ball three times, then are never passed to again. This social exclusion protocol experimentally generates feelings of social pain that allow researchers access to pain theory insights that might otherwise be difficult to measure. Cyberball not only provides a safe and controlled way of experimentally inducing

social pain, but it is also simple for researchers to set up and simple for participants to understand (Hartgerink et al., 2015).

For many who hear about Cyberball for the first time, it is difficult to comprehend how its simplicity can achieve such profound effectiveness. It is hypothesized that this effect of social exclusion occurs through a highly-sensitive social pain detection system that is designed to act quickly and crudely in order to prevent and counteract any social threats to survival (Williams, 2009). The extent to which the effect can be generalized within the context of Cyberball has been a research area of great interest in the time since the methodology was created.

The majority of Cyberball studies maintain a cover story based on the one employed in the original Cyberball study published over two decades ago. That is, participants were told that the purpose of the experiment was to study "the utility of the computer as a tool in mental visualization" without focus on individual participant performance (Williams et al., 2000). Because the effect of the Cyberball exclusion condition on social pain generalizes across a wide array of conditions, and because of the evidence that subjective reports of social pain are not reduced in participants who are told that they are playing with a computer instead of two other human participants, some researchers suggest that a cover story may not be necessary (Hartgerink et al., 2015; Zadro et al., 2004).

Moreover, the ostracism effect is replicated to the same degree when not receiving the ball was to the participant's financial benefit, and when exclusion was performed by outgroup members as ingroup members, even if the members of the outgroup are despised, as represented by KKK hoods placed next to standard Cyberball computer characters (Gonsalkorale & Williams, 2007). Perhaps even more surprisingly, participants who were not passed a virtual bomb that could randomly detonate at any time, a spin on the game Russian Roullette, felt the

effects of exclusion (Williams, 2009). This effect was again maintained when participants were told that the other players could not pass the ball to them because of a lack of network connection from the participant's computer (Eisenberger et al., 2003). Even watching another person experience ostracism is enough for participants to feel its effect (Wesselmann et al., 2009).

Cyberball's origins are rooted in a real-life ball tossing game. In the first iteration of the game, participants were told to wait quietly in a room with two confederates until their experimenter returned. After a few moments, one of the confederates theatrically noticed a ball and started tossing it around (Williams, 1997). These original inclusion and exclusion passing schemes were mimicked in what became Cyberball (Williams et al., 2000).

The lineage of all social exclusion paradigms began with a simple face-to-face discussion design by Geller et. al (1974). In their experiment, two female confederates excluded actual female participants during a conversation. Importantly, a pilot of the procedure showed that simple explicit ignoring of participants resulted in an easily detectable manipulation. So, the researchers developed a set of rules whereby confederates maintained physical orientation and eye contact with participants, listened when they spoke continuously, and briefly answered questions specifically directed to one of the confederates. The exclusion then occurred through frequent interruptions, changes of topic, and lack of interest in any remarks by the participant. The results of this manipulation spurred an interest that would grab the attention of researchers for decades to follow: participants evaluated themselves and the confederates less favorably than controls and rewarded confederates less than inclusion controls (Geller et al., 1974).

Some less popular models of social exclusion have emerged in the time since (Williams, 2007). The Get Acquainted paradigm is performed with a small group of actual participants that

begin with a get-acquainted discussion. Given topics to discuss, participants take turns sharing. After this, participants are separated and asked to name the participant they would most like to work with. After a few minutes, participants are either told by an experimenter that everyone wanted to work with them—inclusion—or that no one wanted to work with them—rejection (Nezlek et al., 1997).

Gardner et al. (2000) designed an elaborate chat room protocol that involved one actual participant and four confederates located in other locations. Each confederate was assigned a typing profile—e.g., fast, hunt-and-peck, lowercase letters, perfect punctuation, no punctuation—to mimic the tendencies participants might see in a chat room with other real participants. In all three conditions, the first confederate would pose a question, the actual participant would be given an opportunity to answer, and then the other three confederates would respond in a predetermined order. The first round of greetings was treated as practice. In the social acceptance condition, the confederate in the third position would respond to the participant's responses with affirmational statements such as "I totally hear you!" or "Cool!" In the interpersonal rejection condition, confederates split into groups of two based on imaginary interests such as sharing a love for an imaginary band. In the collective rejection condition, all four confederates formed a marching band ingroup where the ensuing discussion left the participant out.

Williams et al. (2002) utilized a similar chat room concept with four possible conditions created by pairing in-group or out-group with inclusion or exclusion. Both conditions began with four minutes of conversation designed to engage the participant. In all conditions, one of the two confederates asked the participant whether they went to public or private school. In the in-group conditions, the confederates responded in accordance with the choice of the participant.

In the out-group conditions, the confederates responded with the opposite choice of the participant. Conversation continued for four minutes with engagement of the participant in all conditions. In the inclusion condition, this continued for another five minutes. In the exclusion condition, the two confederates proceeded to ignore the participant for those next five minutes, ignoring any comments made by the now ostracized participant. Though participants reported a high sensitivity to ostracism in chat rooms, a disadvantage to this model is that exclusion might not be as overt as that in Cyberball where the target of each pass is crystal clear.

In the cell phone text messaging procedure designed by Smith and Williams (2004), the actual participant arrived at the lab with one male and one female confederate. The three were seated in triangular formation and told that communication between them would occur through text messaging in order to study the nature of SMS (short text message) communication. The in-group/out-group manipulation was very similar to the one from the chat room procedure. This time, the question asked whether or not participants were smokers. For participants in the inclusion condition, conversation with the participant continued for eight minutes. For participants in the exclusion condition, their messages were entirely ignored and the participant was never addressed by the confederates for eight minutes. The experience for participants was very similar to those from the chat room. Because this was first performed in the early days of text messaging, the phone provided to participants for use in the experiment was delivered with instructions. Excluded participants were sensitive to social pain, despite the lack of nonverbal cues from in-person conversations and this effect overwhelmed any differences that might be seen for members of in- or out-groups.

Zardo et al. (2005) designed an elaborate makeshift train setting where nine participants per session role-played scenarios. Target participants were seated between two source

participants. Targets were informed that they had not invited the two sources to a birthday party from the previous weekend and that they were worried about sitting between them on the crowded train home. Sources were told that they and their fellow source were angry about not receiving an invite to the target's to the birthday party. Sources of ostracism were instructed to talk over the target and completely ignore them. Sources of argument were instructed to argue with and insult the target. This role playing went on for five minutes. Targets and sources of ostracism reported lower and higher need satisfaction than targets and sources of argument, respectively.

Not all models of ostracism rely on real-time exclusion. Some, such as the paradigm designed by Goldfried and Sobocinski (1975) and later replicated by Craighead et al. (1979), rely on asking participants to vividly imagine an experience of rejection. This design sheds light on imagined exclusion, as opposed to real-time exclusion. The finding of greatest interest here was that participants who exhibited a high score on the Irrational Beliefs Test used a higher frequency of negative self-referent self-statements (Craighead et al., 1979).

Twenge et al. (2001) designed the life-alone paradigm. First, participants respond to a personality questionnaire. Based on their answers, the participants are correctly told whether or not they are introverted or extroverted. Random assignment then determined which of the three subsequent types of feedback participants were given. Those in the accepted/high-belonging condition were told that they were likely to have rewarding relationships throughout life including a long and stable marriage and supportive lifelong friendships. Those in the rejected/low-belonging condition were told that they were likely to end up alone later in life and that most of their present friendships would disappear by their mid-20s. The third condition was a negative-feedback control where participants were told that they would endure a lifetime of

accidents and injuries. This model is tuned to feedback about the future based on the present, whereas Cyberball induces momentary exclusion.

In the continuous public goods dilemma game, participants reported pleasure when those who did not cooperate with social norms in a group were ostracised, were likely to ostracise those who did not cooperate, and took pleasure when these uncooperative individuals were excluded from the group (Ouwerkerk et al., 2005). This model is designed from the perspective of the excluder, not the excluded.

Hitlan et al. (2006) utilized a reading scenario model where participants were instructed to assume the perspective of the main character in one of three vignettes. All participants read an introduction to immerse themselves in the situation as an ergonomics engineer who has been happily working for a major automobile manufacturer for the past two years and maintains excitement about their future with the company. For participants in the inclusion condition, the vignette continues with a series of interactions with two Spanish speaking coworkers that offer to teach the participant Spanish. In the Spanish exclusion condition, the two coworkers always speak Spanish, ignore the participant's requests to stop, and exclude the participant in other work-related activities. In the English exclusion condition, the scenario was the same as in the Spanish exclusion condition until the two coworkers ignored and excluded the participant while conversing in English. The reported results include lower levels of organizational commitment and organizational citizenship in those who were excluded, plus lower work group commitment and higher rates of prejudice for those exposed to language ostracism. This model introduces a number of social variables, including putting oneself in another's shoes, imagining exclusion over a long period of time, and being excluded on the basis of language.

A more complex model of social exclusion administration that maintains the ease of use and control of computer-programmed interactions with actual participants is the more recent design of virtual reality worlds. Though the most recent, fifth iteration of Cyberball, allows for far more customization than previous editions (e.g., number of players, player names and images, ball images, number and direction of tosses, popup messages, instructions, and colors), virtual reality worlds allow for the addition of nonverbal cues that more closely resemble human-to-human interaction (e.g., gestures, eye contact, facial expression, body language, proximity, surroundings; Downing & Hales, 2019; Parsons, 2015). Kassner et al. (2012) were the first to test ostracism in immersive virtual environments. In this setting, they were able to replicate the same negative effects of ostracism in social exclusion paradigms.

Cyberball has remained the most popular model of social pain induction due to its balance between ease of use, degree of control, and general ability to replicate findings from more complex models of social pain. The study of social pain with the use of any social pain paradigm is often accessed through reflexive reactions to signs of ostracism as measured through self-report and neural correlates. These two major quantification methods are described at length in the sections to follow.

Quantifying Pain with Self-Report

This section utilizes the descriptions and justifications for the four questionnaires that were specifically selected to capture the wide variety of pain experiences that each participant might have experienced during their time in the experiment. A copy of the four questionnaires can be found in Appendix D. Each specific scale falls into a broader category of related scales, which will be described throughout.

The Wong-Baker FACES Pain Rating Scale (FACES) was selected to act as the primary measure in the statistical analysis portion of the experiment. FACES is one of many types of visual analog scale (VAS) varieties. Due to their straightforward nature, VAS are among the most commonly used pain scales in experimental and clinical settings. All VAS are designed to allow participants to rate their pain with a single value on a minimum-maximum continuum. This presentation style has many subtle variations including choice of reference words at the scale endpoints, use of anchors in the middle of the scale, color presentations, and techniques harnessed to allow participants to select a value (Reed & Van Nostran, 2014). Amidst this variety, the Wong-Baker FACES Pain Rating Scale (FACES) is a more comprehensive choice due to its inclusion of six emotional illustrations (Wong & Baker, 2013). These illustrations decrease limitations in participant interpretation due to language barriers.

While the majority of validation studies for FACES focus on younger populations than the target of this study and utilize Likert-style choices, there is strong evidence that VAS varrations highly correlate with each other, indicating that the specific VAS chosen should not significantly impact its effectiveness (Hicks et al., 2001; Jamison et al., 2002). With this in mind, a slider scale was placed under the FACES anchor points for use in the experimental procedure in order to capture subtle differences between participants that may be lost in whole number, Likert-style options (Treiblmaier & Filzmoser, 2011). Because there is evidence that slider starting points may lead participants to answer differently, the slider scale was programmed to present with no starting point (Liu & Conrad, 2019; Maineri et al., 2021).

The inclusion of emotional displays with tears on scales with faces has been critiqued for use in settings where a pure physical pain measurement is valued. The Faces Pain Scale - Revised (FPS-R) was developed to address these concerns by creating a new set of faces without

tears and smiles (Hicks et al., 2001). Though the biopsychosocial and neuromatrix models would argue that such disentanglement between physical and other forms of pain is impossible (Lugg, 2021; Melzack, 1999). Because of the close relationship between emotional displays and social pain, and the close relationship between social and physical pain, the inclusion of affective factors should be thought of as beneficial for a simple, quick, holistic measure of pain. This more holistic pain measurement has shown a high correlation with other social pain distress indicators, which further supports the use of FACES as a proxy for total pain assessment, including physical and social pain (Williams, 2009).

In each of the three measurement periods that each participant participated in, FACES was followed with the Need Threat Scale (NTS). NTS has become ubiquitous with social pain quantification in many Cyberball studies (Hartgerink et al., 2015). Specifically, NTS was designed by Williams to include all the components associated with the reflexive stage of ostracism theorized to be the primary measurable components of social pain (Williams, 2009). This stage includes feelings of need threat and negative affect. Subcomponents of need threat include belonging, self-esteem, control, and meaningful existence, each of which are devoted five questions on NTS. After answering these 20 questions, participants are asked to answer an eight question subscale that detects positive and negative affect. It should be noted that the affective subscale is not calculated within the standard composite averaged used for the presentation of a need threat score (Jamieson et al., 2010; Sestir, 2020). Because NTS was designed for use in conjunction with Cyberball, the scale also includes three manipulation check questions to verify that participants who were randomly assigned to the Cyberball Exclusion condition experienced more exclusion and a lower percentage of passes than participants who were randomly assigned to the Cyberball Inclusion condition.

The four need threat subscales each represent scores for threat to belonging, self-esteem, control, and meaningful existence, with higher scores indicating higher threat. A threat to belonging refers to a signal of physical or mental distancing between one's self and others. A threat to self-esteem occurs when an individual begins to consider that the ostracism they are experiencing is due to who they are generally or what they have done specifically. A threat to control occurs when an individual is unable to engage with the ostracizer and to change their actions toward inclusion. A threat to meaningful existence occurs when an individual feels invisible or akin to being dead due to ostracism. These are detection processes that occur before a conscious effort to attribute the motivations, meaning, and relevance of the behaviors that initiated feelings of social pain, and are associated with reductions in positive affect and increases in negative affect, including anger and sadness (Williams, 2009). Previous work has questioned the ability for these, and other, subscales to elucidate individual components of need threat. Taken together, however, NTS does appear to be a valid measure of composite need threat (Gerber et al., 2017; Reise et al., 2013).

Because the McGill Pain Questionnaire (MPQ) was originally designed not only to quantify pain but also to inform differential diagnoses and respective treatment options in clinical and surgical settings, this scale is excellent at differentiating between discriminatory pain signals. The Short-Form McGill Pain Questionnaire (SF-MPQ) was designed to distill the most important components of the MPQ so that this scale could be of more use to those with time constraints, such as researchers. SF-MPQ features an 11-item physical pain and a four-item affective subscale in addition to a Present Pain Intensity slider scale and an alternative verbal rating of total pain (Katz & Melzack, 2011; Melzack, 1987). Previous research has effectively used this four-item affective subscale as an index of social pain (Chester et al., 2016). Because

the intensity ratings and descriptives correspond with words, the SF-MPQ falls into the larger category of verpal pain scores, verbal rating scales, and verbal descriptor scales (Karcioglu et al., 2018). For these reasons, the SF-MPQ was included as the third questionnaire.

The SF-MPQ-2 was developed to discriminate between neuropathic and non-neuropathic pain (Lovejoy et al., 2012). Because this experiment was not specifically interested in this type of pain and because the previous version had been utilized in the context of social pain, the SF-MPQ was ultimately chosen as the superior option.

The Hurt Feelings Scale (HFS) was included as the fourth scale and was developed to clarify hurt feelings as a unique emotion often left out of emotional analyses by researchers and scholars (Leary & Springer, 2001). DeWall et al. (2010) utilized this scale as their subjective measure of social pain due to its relation to the experience of social exclusion and its lack of conflation with other negative emotions.

The Borg Discomfort Scale (CR 10+) is a scale of preference within exercise science and related fields. It is used for a variety of pain and physical exertion measurements. A unique characteristic of this scale is that the highest anchor point, 10, is calibrated to the maximum discomfort each participant has experienced. That is, if the pain in the experiment is 1.5 times the maximum discomfort a participant has ever experienced, the participant would rate the pain as 15 (Jessee et al., 2017; Mattocks et al., 2017). The other category of pain rating tools that warrant mention are Numeric Rating Scales, which typically refers to a relatively simplistic 11-point numeric scale with anchor point labels at the two ends of the scale (Karcioglu et al., 2018).

Neural Correlates of Social Pain and Physical Pain

The emergence of shared language to describe physical pain and social pain (e.g., *that glass shard hurt my foot* and *that insult hurt my feelings*) provided the first hint that these two

pain systems may be related. Numerous studies have contributed findings in support of the claim that physical pain and social pain involve overlapping neural structures, with data pointing to overlapping feelings within the affective domain as regulated by the anterior cingulate cortex (Eisenberger, 2012).

Papez (1937) presents the earliest work to suggest that the then-termed cortex of the cingular gyrus is a convergence of impulses resulting in the experience of emotion. In a rather influential experiment 25 years later, Foltz and White (1962) extended support for this cingulum theory and its significance in the emotional processing of pain through the surgical disconnection of the cingulum fasciculus (cingulumotomy) in human patients with severe chronic pain. After cingulumotomy, patients sustained their ability to localize pain, but told researchers that their "pain no longer bothers them." A much more recent meta-analysis of 46 functional magnetic resonance imaging (fMRI) studies involving 940 participants found three ACC regions to be activated during social rejection—subgenual ACC, pregenual ACC, and anterior midcingulate cortex (aMCC)—localized the aMCC (a region within the dACC) as the potential specific overlapping region associated with the affective component of both physical and social pain (Rotge et al., 2015).

While Rotge et al. (2015) arrive at a single, strongly supported area of the brain that displays shared activity in physical pain and social pain, the large body of work drawn upon for their meta-analysis and utilized for other meta-analyses of the same topic have arrived at conclusions that are directly at odds with each other. Eisenberger popularized the conversation in 2003 with Williams, three years after Williams published the first study with Cyberball in an article that used fMRI to show an increase in brain activity in the dorsal anterior cingulate cortex (dACC) and the right ventral prefrontal cortex (RVPFC) during social exclusion from Cyberball

(Eisenberger et al., 2003; Williams et al., 2000). This article implicated the dACC as a distress center activated during pain detection that is physical or social in kind and the RVPFC as a self-regulatory region that can lessen these feelings of distress (Eisenberger et al., 2003). This article launched a debate that has continued for nearly two decades.

The majority of studies continued to support the dACC as the overlapping region in physical and social pain. But one meta-analysis published in 2013 found that social rejection does not operate on the same neural matrix as physical pain. Instead, their multi-level kernel density analysis, which was designed to minimize biases such as the false-positives that might otherwise occur from analyzing so many brain regions simultaneously, found activation of the anterior insula (bilaterally), left ACC, and left inferior orbito-frontal cortex during exclusion from Cyberball. Notably, the dACC was not significantly activated. Another type of experimentally induced social pain—reliving rejection by a significant other—highlighted the right anterior insula, right ACC, left inferior orbito-frontal cortex, and right caudate nucleus. This analysis also did not show the dACC as significantly activated (Cacioppo et al., 2013).

This analysis is with direct odds with the Rotge et al. (2015) meta-analysis reported above. The disadvantage of the Cacioppo et al. (2013) is that it was published two years prior with 696 less participants than the Rotge et al. (2015). But taking the Rotge et al. (2015) as the presiding truth is not fair, either, due to the methodological choice to only include studies that reported activation within the defined ACC region. They began with the assumption that the ACC was implicated with social pain and aimed to further clarify the purpose of its subregions.

The latest meta-analysis of neural activity social exclusion such as Cyberball sides with Cacioppoi et al. (2013) in that the dACC did not show reliable activity during social exclusion (Mwilambwe-Tshilobo & Spreng, 2021). Instead, Mwilambwe-Tshilobo and Spreng (2021)

argue that a functionally integrated network of brain regions, including the bilateral ventral ACC, right posterior insula, right superior frontal gyrus, left inferior frontal gyrus, left posterior cingulate cortex, and left occipital lobe, is reliably engaged through social exclusion from Cyberball and other social exclusion paradigms. While some of these regions appear to be the same or very close to regions activated by physical pain, this is not necessarily where the focus should lie. Even if a single region such as the dACC overlapped, brain regions constantly interact with each other in highly specific patterns. Taken together, a wider range of entry points into novel treatments for the feelings resulting from social exclusion (Mwilambwe-Tshilobo & Spreng, 2021).

While fMRI is often relied upon in isolation to extrapolate neural mechanisms, the majority of such imaging techniques merely provide topographical haemodynamic associations of imperfect tasks on hyper-specific brain regions through the mapping of relative metabolic activity quantified through brain blood flow before and after a particular experimental procedure. Such a statement should not be confused with one that calls for the removal of such imaging as a technique. Instead, it indicates that false assumptions about fMRI methodologies often lead to false conclusions that discount the value of a multimodal approach. The first false assumption is that the tasks participants undergo are able to successfully isolate the cognitive process of interest. The second false assumption is that hyper-specific brain localizations are meaningful in isolation. More likely, tasks elicit complex interactions of brain activity within a neural matrix, some of which occur on scales of time and space that are unrecognizable by even the most optimized fMRI setups. In the case of pain, fMRI fails to account for signaling that occurs outside of the brain, such as at the level of the affector, spinal column, or glial cells. Furthermore, it may misattribute excitation and inhibition and blend directional function-specific processing

that occurs in a bottom-up or top-down fashion. Instead, fMRI ought to be used to identify

hypotheses for further study and to support otherwise established theories, not to draw detailed

conclusions in isolation (Logothetis, 2008).

Decreasing Social Pain with Physical Interventions

An alternative method to help understand how pain works—a concept that is clearly

difficult to gain traction with, especially pain that is not caused by acute impact but is

psychological in nature and hidden from plain sight—is to explore the dynamics of how the pain

experience of interest can and cannot be ameliorated. Just as physical pain can be lessened by

both physical and psychological interventions, there are signs that psychological pain can be

reduced similarly. The first published study to attempt such an approach used a commonly

employed, low-risk psychological intervention to model social exclusion has revealed that a

pharmaceutical pain reliever (acetaminophen/Tylenol) typically employed to reduce the

experience of physical pain can also reduce multiple forms of social pain, including the social

pain induced by Cyberball. This included an fMRI study that found that exclusion during

Cyberball increased reports of social pain and activity of the dorsal anterior cingulate cortex

(dACC) and that administration of acetaminophen reduced reports of social pain and activity in

the dACC. This added support for the claim that social pain and physical pain have overlapping

neural mechanisms (DeWall et al., 2010). Neural mechanisms measured during the Cyberball

procedure and self-reports measured immediately after the Cyberball procedure are generally

thought to capture the reflexive stage of ostracism which is defined as social pain (Hartgerink et

al., 2015).

In the time since this study was published, many other drug-based interventions targeting

a variety of mechanisms have been designed in an attempt to better understand the mechanisms

that moderate the perception of social pain. Through a different study design, one study replicated the finding that acetaminophen decreases social pain, as represented by self-reports on the Hurt Feelings Scale before and after Cyberball exclusion (I. D. Roberts, 2013). A couple of studies have suggested that intranasal administration of oxytocin may protect against the negative effects of social exclusion in certain populations, such as those high in horizontal collectivism (scoring high in perception of self and other around them as part of a group) and women (Henningsson et al., 2021; Pfundmair & Echterhoff, 2021). A third oxytocin study found that oxytocin reduces the neural response associated with exclusion, but not self-reported feelings of rejection (Petereit et al., 2019).

Preller et al. (2016) showed that the preferential serotonin (5-HT) 2A/1A receptor agonist, psilocybin, reduced the neural activity associated with exclusion from Cyberball. This was quantified through fMRI, which measures change in blood flow, and magnetic resonance spectroscopy (MRS, which measures change in concentration of either neurotransmitters or neuro metabolites) imaging of the dACC. Choi (2013) found that capsaicin delivered through the ingestion of tomato soup spiced with chili pepper reduced ratings on a retrospective need satisfaction index. Another study showed that Rifaximin, a poorly absorbable antibiotic, reduced the neural activity associated with exclusion from Cyberball as quantified by a decrease in beta-1 power in widespread regions of the frontal cortex and the left anterior cingulate gyrus measured with magnetoencephalography (MEG; Wang et al., 2018). Frye et al. (2014) showed that 3-4-Methylenedioxymethamphetamine (MDMA) reduced the effect of exclusion from Cyberball on self-reported measures of social pain—namely mood, self esteem, and perceived rejection—and decreased respiratory sinus arrhythmias, an index of social engagement and emotional regulation. Deckman et al. (2014) showed that marijuana use reduces the effects of

exclusion from Cyberball, as measured as by the Need Threat Scale. Taken together, these studies create a constellation of findings that support the use of various drugs in the form of psychedelics and pharmaceuticals to decrease the social pain associated with exclusion from Cyberball. Unfortunately, each study uses slightly different measures and protocols. Though many of these measures claim to be proxies of social pain, their differences make direct comparisons of relative efficacies and implicated mechanisms of improvement difficult.

Added to this mix of social pain modulation through physical interventions are a number of studies that failed to decrease the social pain associated with exclusion from Cyberball. Despite the widespread consumption of alcohol in social contexts as a coping strategy for social stress, a well-powered study reported that alcohol intoxication did not impact mood and needs satisfaction compared to sober participants (Fairbairn et al., 2021). Following the previous finding, a smaller-scaled study showed that a moderate dose of alcohol to hazardous drinkers did not impact the effect of exclusion from Cyberball based on NTS scores (Buckingham et al., 2016). Bershad et al. (2019) found that microdoses of lysergic acid diethylamide (LSD) did not impact the effect of exclusion from Cyberball based on positive mood ratings. Another study found that cannabidiol (CBD) did not impact the effect of exclusion from Cyberball as measured by feelings of social rejection and responses to negative emotional stimuli (Arndt & de Wit, 2017). Miller et al. (2014) found that glucose did not reduce social pain induced by Cyberball. Because this experiment did not yield changes in social pain, it is unlikely that the pathways stimulated by glucose are involved in its regulation. Statistically significant or not, this model of pain treatment exploration allows researchers to narrow the fields of the brain that show promise for further investigation.

Though these studies did not see the hypothesized significant effects, their publication is important as a catalog of treatments and their associated mechanisms that were not effective or might not be involved with the social pain pathways. Publication bias toward significant effects has historically withheld such information. It is imperative to share all results, significant or otherwise, in order to most-efficiently inform future study design. Interventions as simple as editorial statements to researchers that remind them of the importance of reporting negative findings may be effective in increasing the regularity of the practice (Blanco-Perez & Brodeur, 2020). Because truly Open Science has not yet been realized, many actionable recommendations to motivate detailed reporting and best practices for reporting have been suggested to improve the quality and speed of all science moving forward (Aguinis et al., 2020).

Mixed evidence aside, these drug-based approaches may be more useful in selectively supporting hypotheses of the mechanisms that underlie social pain than treating or preventing social pain in otherwise healthy populations due to their unintended side effects. Furthermore, specific drug treatments may only be effective for specific populations with specific predispositions. Therefore, the potential for non-drug treatments to reduce the impact of social pain in an otherwise healthy, diverse population with lower potentials for unintended consequences and with potential to positively impact a wider population is needed.

Riva et al. (2012) attempted a non-drug approach to the reduction of social pain that was reported to be successful, but that may fall short of the lack of side effects that his category of treatment is aimed towards. In this study, researchers targeted the right ventrolateral prefrontal cortex (rVLPFC) with transcranial direct current stimulation (tDCS). They found that this noninvasive brain polarization reduced the effects of exclusion from Cyberball as measured by pain unpleasantness and hurt emotions. A thorough review of potential side effects from tDCS

indicates that approximately 20% of participants rate tDCS procedures to be mildly unpleasant and that approximately 70% of participants report tingling, approximately 35% of participants report fatigue or tiredness, approximately 10% of participants report headaches. Though these numbers are comparable to active and sham conditions, the net benefit of use in the real world during or after social exclusion remains untested and unclear (Z. Zhang, 2020). Furthermore, setup in the real world requires precise protocols in order to correctly target the precise brain region of interest, which may be difficult for the average user.

Aydin et al. (2012) found that participants who experienced exclusion from Cyberball but did not have a dog to the testing room reported lower ratings of mental well-being, as measured by a composite score of the Satisfaction with Life Scale, Meaning in Life Questionnaire, Rosenberg Self-Esteem Scale, and general feelings of social acceptance than participants who did have a dog in the testing room. Though these researchers designed a protocol that does meet the safe, non-drug standards, they did not explicitly measure the impact of exclusion from Cyberball on the social pain.

Another protocol by Ikeda and Takeda (2019) used an extremely safe, non-drug intervention—holding soft or hard cushions during exclusion from Cyberball—but found that holding a soft object increased ratings as compared to holding a hard object on four questions selected from the Need Threat Scale and increased grand-averaged contingent negative variation (CNV, an indication of heightened expectation and anticipation) of event-related potentials measured by electroencephalogram (EEG). That holding a soft cushion did not decrease the social pain from Cyberball exclusion as compared to the hard cushion was in opposition of their expected results. They did not test how the hard cushion ratings compared to participants who experienced Cyberball without holding an object.

If percussive therapy is able to effectively reduce social pain in physically healthy participants, it may be able to successfully fill the need for a simple, accessible, safe non-drug intervention to reduce the pain from Cyberball. Percussive therapy benefits from the ability to be applied with immediate effect at any time. And besides accounting for potential side effects, drugs take time to reach maximum potency, which may miss the critical period of intervention if reserved for ameliorating social pain after a painful experience has occurred.

This exploration seeks to expand on this tradition of examination by measuring whether a tactile stimulus often utilized for physical pain modulation may also decrease social pain through a similar neural pathway. The use of a popular consumer device—Theragun—offers a high degree of experimental control in the application of this tactile stimulus, commonly referred to in the literature as percussive therapy.

Decreasing Social Pain with Psychological Interventions

Before exploring the percussive therapy literature, an exploration of psychological and interventions for social pain is warranted. While research on the effectiveness of pain reduction through non-physical interventions is relatively limited, the psychological toolboxes provided by various forms of psychological therapy seem like a good fit for those suffering from social pain (Sturgeon & Zautra, 2016). Within the framework of cognitive-behavioral therapy (CBT), there is evidence that a therapist might be able to effectively introduce strategies that address the deficiencies in social function that may have led to social pain and teach communication strategies that can help decrease feelings of alienation and misunderstanding in painful relationships (Linton & Ryberg, 2001).

Skills work from acceptance and commitment therapy and mindfulness-based stress reduction might help increase the psychological flexibility necessary to cope with past and future

painful interactions (McCracken & Vowles, 2014). Loving kindness meditation has been shown to improve interpersonal factors through the expansion of spreading love and kindness from the self to others (Sturgeon & Zautra, 2016). Less specifically, social intelligence skills training outside a specific psychological framework have been shown to improve the quality and duration of social relationships (Zautra et al., 2015). Finally, positive psychology has shown promise as an effective method to reduce the distress associated with social pain through expressing forgiveness, gratitude, prosocial behaviors, compassion, enjoyment, optimism, and meaningful goal setting (Flink et al., 2015).

Psychological therapy may be initially sought out well after initial detection of social pain and therefore may be particularly beneficial for the reflective and resignation stages of ostracism, as described by Williams (2009). In these stages, cognitive processes work to match experiences of ostracism with personal characteristics. Psychological therapy may help individuals break out of this cycle by pointing out misattributions and fixations and building new skills to better fortify needs that were previously threatened for future interactions.

Other similar interventions include psychological trainings for caregivers, healthcare providers, teachers, and romantic partners. By highlighting the importance of compassionate and empathetic responses in the health outcomes and relationships of people they care about, support systems at all levels might be better equipped to reduce the distress associated with social pain (Sturgeon & Zautra, 2016). Because of the low level of risk involved with these psychological interventions and the relatively long skills learning and implementation timeline, they may be particularly well suited for combination with other effective physical interventions that can be applied instantly.

Percussive Therapy

Percussive therapy is a relatively new category of physical treatment which defines the combination of pressure and vibration stimuli delivered in a localized fashion (Konrad et al., 2020; Roberts, 2020). So far, experimental evidence specific to percussive therapy mainly suggests that the modality decreases muscle tension (as measured by an increase in range of motion) and reduces delayed onset muscle soreness—physical pain induced through certain forms of exercise, especially eccentric muscle contractions under maximum weight. The implicated mechanisms of action for these processes include thixotropy, fascial fluid distribution, increased tissue temperature, and increased local blood flow (Martin, 2021). Additionally, in a research partnership with Biostrap, Therabody found initial support for the use of a Theragun to improve various measures of sleep and recovery quality. Of distinct relevance to the present work, subjective pain ratings in that study decreased by an average of 9% after the use of a Theragun (Biostrap, 2020; Therabody, 2020). It should be noted that these longitudinal, post-treatment improvements were based on a comparison to within-subject baselines without comparison to a control group. Therefore, it remains unclear the precise mechanism through which these improvements occurred.

Despite a relative lack of evidence-based guidelines, the adoption of percussive therapy in healthcare and consumer settings is increasingly widespread. In an attempt to better understand how percussive therapy is being used, one survey with reports from 425 athletic trainers and physical therapists found that 59% reported using percussive therapy for pain modulation (Cheatham et al., 2021). While health professionals that work with clients have the benefit of observing client outcomes with real-time interactive feedback, the current literature lacks research aimed at clarifying the neural mechanisms implicated with the many anecdotal

reports of percussive therapy's contribution to pain reduction. If a high degree of clarification can be reached in the future, guidelines may be strengthened for the application of percussive therapy with the purpose of pain reduction and other specified outcomes. The present study aims to move this work forward.

In the time since this project was conceived, one study about the use of percussive therapy, specifically, to treat pain other than that derived from delayed onset muscle soreness has been published. At face value, the authors report that the combination of ergonomic advice and Theragun treatment improve ratings of low back pain in bus drivers, as compared to a control group without any intervention. Unfortunately, the paper lacks many of the components and characteristics that a strongly-supported scientific article might utilize to arrive at their conclusion statement. Cosmetic errors in the correct use of English words and grammar aside, the major summary of vibration therapy in the introduction: "Vibration therapy improves muscular strength, power improvement, and kinesthetic awareness, improves flexibility and reduces pain. Vibrations diminish the perception of pain through the mechanism of pain gait theory" employs the use of definitive statements for theories that the cited sources do not claim to support. Even more concerningly, Graph 1 for the data reported in Table 1 does not remotely resemble the same numbers. Moreover, Graph 2 seemingly reports the same numbers displayed in Table 2, but Table 2 is labeled as "Pretreatment" while Graph 2 is labeled as "Post-Treatment." Pre-treatment numbers for one outcome variable and post-treatment numbers for the other outcome variable do not appear to be reported at all, making inferences about change over time impossible. Due to a catastrophic lack of control over background theory and data presentation, a corrected concluding statement is unintelligible (Mansuri & Patel, 2021). It is concerning that this article passed through the double-blind peer review process boasted by the International

Journal of Science and Research (IJSR), as evidenced by the result of this article within the IJSR website's search engine and the statement on the journal website's home page (*About the Journal*, 2021; *Search Results for Effectiveness of Theragun and Ergonomic Advice in Patients with Low Back Pain among Bus Drivers*, 2021).

The term percussive therapy includes a number of variables both physical— vibration frequency, vibration amplitude, application pressure, contact material—and intrinsic (e.g., expectation, distraction, sensitivity) that might contribute differentially to percussive therapy outcomes. Furthermore, the interaction between the variables may change based on the specific physical settings of each and the specific intrinsic characteristics of the individual being treated. If these dynamics are to be understood with greater precision, a new body of studies with rigorous and robust designs are required.

Previous work specific to percussive therapy posits that application with more force primes muscles for intense activation. Application with less force, sometimes referred to as 'floating,' is intended to promote a relaxation response. Supported in the field, this floating technique was used before bed by participants in the aforementioned sleep study designed by Therabody and Biostrap to effectively promote relaxation, as quantified by improvements in various sleep metrics including decreased sleep latency and increased sleep efficiency (Biostrap, 2020; Therabody, 2020). The same floating technique was employed in the present study.

Vibration and Pain Modulation

In a comprehensive review of neuromuscular sensation from local vibration, Souron et al. (2017) assert that muscle spindles are thought to be the most sensitive vibration detectors in the body, though Golgi tendon organs and Pacini, Meissner, Ruffini, and Merkel receptors are all thought to be sensitive to vibrations of specific frequencies and amplitudes. Primary (Ia) and

secondary (II) afferents innervate these muscle spindles and relay the detection messages to the corticospinal system. The smallest tested vibration amplitudes, those less than 0.5 millimeters (mm), preferentially activate Ia afferents. Larger amplitudes primarily activate mainly Ib and II afferents. Vibrations of 20 to 60 Hertz (Hz) stimulate II afferents and Ia afferents are most sensitive during stretching and isometric contraction. The Ia afferents control a muscular contraction called the tonic vibration reflex due to their tendency to excite alpha motorneurons. This pattern has been observed for frequencies of vibration from 20-200 Hz in the majority of muscles around the body. While this article was not a review of pain sensation, gaining a better understanding of which sensory neurons are involved in the detection of is important. The rest of this section focuses on specific applications of local vibration for the purpose of studying pain modulation.

In line with the recruitment of differential afferents at different frequencies and amplitudes, there is evidence that the application of vibration may cause hypoalgesia or hyperalgesia based on frequency and amplitude. One study showed that at frequencies of 12 Hz and 50 Hz with an amplitude of 1.0mm, and 80Hz with an amplitude of 0.5mm, pain from pressure applied to the finger decreased. At 80 Hz and 1.0mm, the effect changed directions, causing an increase in pain. These changes in pain perception were directly related to Pacinian activation. This provides evidence that vibration interacts differently with pain perception based on the variables of frequency and amplitude and that Pacinian corpuscles may be involved in this interaction (Hollins et al., 2017).

Hollins et al. (2017) use this evidence to support a theory of pain perception proposed by Vierck et al. (2013) whereby pain signaling in brain area 3a of the primary somatosensory cortex and tactile signaling in areas 3b and 1 are antagonistic at low or moderate levels of activation and

agonistic a high levels of activity. This is an example of brain imaging being paired with other experimental methods to strengthen a hypothesis about the nature of pain modulation.

Staud et al. (2011) compared the variable of homotopic and heterotopic application of vibration at 100 Hz for pain modulation of a noxious heat stimulus. They reported a 40% reduction in homotopic pain and a 32% reduction in heterotopic pain. In part due to the choice to perform this study with participants that had either pre-existing conditions that feature chronic widespread pain, or localized musculoskeletal pain, or were healthy controls, these pain sensation and modulation patterns supported their theory that vibro-tactile analgesia occurs through Aβ mediated afferent inhibition of dorsal horn nociceptive neurons. Previously, this population had been shown pain modulation deficits in highly noxious conditioning stimuli targeted at Aδ and C afferents.

Previous work has supported the theory that vibro-tactile analgesia occurs through the inhibition of dorsal horn neurons. Of note, 25 Hz did not show evidence of change in primary somatosensory activation in response to heat nociception, but 200 Hz did (Tommerdahl et al., 1999).

A meta-analysis of the use of vibration for pain control during dental injections in children showed no statistically significant difference between vibration and control groups, as measured by the FACES pain scale (Faghihian et al., 2021). But there was a reported benefit of vibrating devices plus cold on pain during vaccination and phlebotomy in children (Gerçeker et al., 2018; Taddio et al., 2015). Neither the DentalVibe nor the Buzzy devices used in these experiments detail the frequency and amplitude of their devices but the Buzzy is vaguely described as using high frequency and low amplitude (Buzzy, 2021).

Chandrashekhar et al. (2021) reported an improvement in pain after the application of a wearable focal muscle vibration device called the Myovolt, as measured by on the Brief Pain Inventory—Diabetic Peripheral Neuropathy. The applied frequencies ranged from 35 to 120 Hz.

Lurie et al. (2018) reported a 34% reduction in pain for individuals who developed low back pain during standing, as measured by a visual analogue scale. Vibration was applied at 54 Hz with a vibrating massage belt called the Zewa Spa Buddy. Interestingly, the pain regressed back to full strength after only 12 minutes post-vibration. The authors attribute the decrease in pain to the Gate Theory from Melzack and Wall (1965), which posits that a non-noxious stimulus to the skin at the site of pain activates large diameter Aβ fibers that block the activity of smaller fibers that communicate with the brain. The authors speculate that a longer vibration duration of 45 minutes might have increased the duration of the effect, based on previous findings (Lundeberg et al., 1984).

Cheatham et al. (2017) showed that pain thresholds increased most after application of a 33 Hz vibrating roller (GRID VIBE) to the quadriceps, as quantified by an algometer. Rolling without vibration also resulted in increased pain thresholds and so did the non-rolling control, though by a statistically lower amount than the increase reported by those in the vibrating roller condition. This shows that there were a number of factors at play, including the pressure applied by the roller and the change in pain sensitivity from the first algometer measurement to the second algometer measurement.

Kumru et al. (2021) found that vibration frequencies of 50 Hz and 150 Hz decreased amplitudes of the Hoffmann Reflex (a measure of nerve conduction along the tibial S1 pathway) and T wave (a measure of repolarization). This caused a greater reflex suppression than the 250

Hz vibration. No change in perceptions of warmth and heat pain perception thresholds were reported.

While it is encouraging to see a diverse mixture of studies attempting to clarify the interaction of vibration with pain, the massive procedural differences make direct comparisons and generalizations past these specific vibration and participant conditions difficult. Standardization of variables and systemization of testing would improve this going forward. But such challenges are not unique to this relatively young field of study.

Manual Massage and Pain Modulation

At its most basic and agreed-upon level, massage is generally defined as manipulation of soft tissue (Kennedy et al., 2016). As a much older field of study than vibration, massage researchers and health practitioners have contributed to an increasingly large body of literature, spanning more than 300 clinical trials and dozens of systematic reviews, in an aim to clarify the effectiveness of massage as a modality to reduce pain. The broad category of treatment, however, has exhibited a number of challenges to reaching the level of clarity that would be useful to those giving or seeking massages. A few of the most common types of massage therapy, which are designed to be more systematic in their application than general massage, include Swedish massage, chair massage, sports massage, and deep tissue massage. These massages might be administered by a number of health practitioners including licensed massage therapists, chiropractors, physiotherapists, reflexologists, and folk healers. Each practice as administered by each practitioner varies by duration, intensity, and technique, making standardization of application difficult (Miake-Lye et al., 2019). Moreover, each participant exhibits pain in a wide variety of locations from the face to the foot from a wide variety of conditions from diabetic neuropathy to stiffness from sitting for too long.

Miake-Lye et al. (2019) set out to rate the quality of all the evidence from all the systematic reviews in the field. The researchers found that 32 of 49 systematic reviews were high quality, based on a modified Assessing the Methodological Quality of Systematic Reviews (AMSTAR) rating system. The most definitive evidence from these high quality reviews was rated low in strength based on the lack of rigorous methods in big samples for specific conditions. These reported potential benefits of massage for pain in the shoulder, neck, low back and from labor, cancer, arthritis, surgery, exercise. As such, the state of clarity of evidence in the massage field for pain modulation remains low (Miake-Lye et al., 2019).

Isolation of Vibration from Percussive Therapy Device

As described in detail above, there are many variables in the presentation of percussive therapy. Much of the existing work has brought attention to specific effects of specific vibration amplitudes and frequencies under specific conditions of pain induction within a specific population. Additionally, the studied mechanisms of percussive therapy have primarily been approached through physical considerations, such as the effect of percussive therapy on physical pain sensation or other movement based measurements.

The present experiment aimed to isolate the effect of vibration from percussive therapy on a socially-derived pain induction method. Compared to the existing literature, the vibration was applied at a moderate frequency—40 Hz—with a very large amplitude of 16 mm. A series of six carefully designed conditions spread three over three phases were designed to reduce confounding factors that may have shielded the unique effect of vibration, should it exist. The goal of the first Pilot Phase was to establish that participants within the conditions specific to this lab reacted to the social pain induction paradigm as expected and that these reactions were detected by the included self-report outcome measures. The second Experimental Phase then

aimed to measure the specific effect of vibration on pain modulation from a socially-derived pain induction method compared to an otherwise identical non-vibration control. The goal of the third Replication Phase was to extend the findings from the Pilot Phase by collecting more data in the two replicated conditions that involved pain induction and by adding two additional control conditions to compare the effect of vibration in participants without increased levels of pain. All the details for each phase are described below.

Pilot Phase

The Pilot Phase was designed to replicate previous Cyberball findings within the setting of this specific experiment (i.e., that Inclusion from Cyberball does not increase pain and that Exclusion from Cyberball does increase pain), establish test-retest reliability for FACES, and identify any unforeseen areas of procedural confusion or human error, should they arise. In order to clarify these concepts, two primary and three secondary confirmatory hypotheses were preregistered (see Appendix II).

Pilot Phase Methodology

Pilot Phase Hypotheses and Planned Analyses

All the hypotheses and planned analyses listed in this methodology section were preregistered through the Open Science Foundation prior to any data collection (see Appendix III for link). All planned analyses were intended for use with FACES, unless otherwise noted. The first primary hypothesis was designed to confirm that pain scores for participants who experienced Inclusion from Cyberball would not differ at the three measurement periods: Baseline, Post-Cyberball, and Post-Video. The second primary hypothesis was designed to detect a change in pain scores for participants who experienced Exclusion from Cyberball over the

course of the same three measurement periods. The planned analysis to inform each of these primary hypotheses was a one-way repeated measures analysis of variance (ANOVA).

Three secondary comparisons were designed to localize the sources of difference within the ANOVA. First, it was expected that a repeated-measures t-test would reveal an increase in pain scores for participants who experienced Exclusion from Cyberball from the Baseline to Post-Cyberball measurement periods. Second, it was expected that another repeated-measures t-test would show no change in pain scores for participants who experienced Exclusion from Cyberball from the Post-Cyberball to Post-Video measurement periods. Third, it was expected that a between-participants t-test would reveal that participants who experienced Exclusion from Cyberball would report higher levels of exclusion than participants who experienced Inclusion form Cyberball at the Post-Cyberball measurement period. Only this last analysis was to be performed with the manipulation check items from the Need Threat Scale. Any additional analyses performed beyond these five were exploratory in nature and in response to outstanding questions that resulted from the primary and secondary analyses. Each analysis was reported below with in-text raw descriptives and graphical visualization. Each graph includes a y-axis that represents the full range of the scale and error bars that were calculated through adjusted marginal means to account for the between-participant variabilities that were controlled for in the within-participant design, unless otherwise noted (Cousineau, 2005).

Pilot Phase Participants

Because this experimental procedure is novel in many ways, the studies of closest design were relied upon to provide the assumptions that were necessary to perform an *a priori* analysis in the statistical program G*Power (see table in Section 2 question 7 of Appendix I; Faul et al., 2009). In a meta-analysis of over 120 Cyberball studies, the ostracism effect—of which social

pain is a major part—translated to an average Cohen's f of 0.70 (Hartgerink et al., 2015). This effect size was adopted for the Pilot Phase *a priori* analysis. Acetaminophen's effect on social pain—a physical remedy for social pain that inspired the current experimental design—reported effect sizes in another measurement modality that further support the use of this large effect size. Relative activation of areas within the dorsal anterior cingulate cortex (dACC), translated to a range of Cohen's f from 0.27 to 0.92 (DeWall et al., 2010). Additionally, a conventionally-used power of 0.80 was chosen (Pataky et al., 2018). These assumptions were entered into G*Power and resulted in an output that called for 14 participants (seven per condition) in the Pilot Phase.

Participants were recruited through a multifaceted recruitment strategy that included the posting of flyers on physical bulletin boards in a variety of on-campus academic and social buildings, tabling outside of Kline Commons, and posting a digital flyer on the Bard Students Facebook group (see Appendix F for flyer). Upon scanning the QR code on the physical flyer or clicking the hyperlink on the virtual flyer, recruits were directed to a welcome page that informed them of the general nature of their participation and an eligibility survey (see Appendix A). Eligible recruits were taken to Calendly, where they had the option to schedule any available 30-minute testing session that best suited their schedule. Scheduled sessions required participants to provide their name, email address, and phone number in order to automatically enter the booking into the participant and the researcher's Google calendars. The description of the calendar event provided participants with a basic dress code and meeting location. In accordance with the preregistered *a priori* analysis, 14 participants were recruited for the Pilot Phase.

Pilot Phase Materials

Participants read and answered questions on a Late 2013 27-inch iMac with a 3.2 GHz Intel Core i5 processor, 16 GB 1600 MHz DDR3 memory (Apple, 2013). This computer was

equipped with an ethernet connection to a very strong network with upload and download speeds both always at a minimum of 500 mbps. This was important so that the large, YouTube-hosted video did not buffer while streaming during testing.

Everything presented to participants on the computer was hosted on Qualtrics and displayed through a fullscreen Google Chrome tab in Incognito mode so that the progress of previously-loaded surveys from previous participants did not impact the loading of each new survey.

The presentation of all text, questions, and tasks was customized with HTML and JavaScript code to optimize their presentation on the single in-lab computer used for testing. Four questionnaires—Wong-Baker FACES Pain Scale (FACES), Need Threat Scale (NTS), Short-Form McGill Pain Questionnaire (SF-MPQ), and Hurt Feelings Scale (HFS)—were adapted to the question presentation tools provided within the Qualtrics platform. All four questionnaires were presented to participants three times. Because NTS was originally designed for presentation directly following Cyberball, a couple of slight modifications were made. First, the general direction to answer based on feelings "during the game" was changed to "past 3 minutes" for the first presentation of Cyberball, since no game had been played yet. Second, any reference to the game or players in this first presentation was simply removed from the wording of that particular item. Three measurement periods were used to get a better understanding of within-participant changes over the course of the experiment. FACES was the primary measure due to its ability to capture a wide range of pain, not NTS. So the application of NTS in this way was intended to be exploratory.

Cyberball was embedded in Qualtrics and hosted by the custom link provided by the Cyberball Configuration Builder (Dovishaw, 2020). The video was also embedded in Qualtrics

and hosted by YouTube (*Video*, 2021). The presentation choices finalized before the start of this phase were the basis for the Qualtrics surveys that were included in the preregistration (see Appendix III for links to all materials).

Pilot Phase Procedure

If participants had Google Calendar notifications turned on, they received an event reminder a half hour before their scheduled session. Because it was not a requirement for participants to have these notifications turned on, the researcher also texted participants approximately a half hour before their session. The message contained the name of the participant, the time and location of the session, and a custom link to reschedule their session through Calendly, should they have wanted to reschedule their session. All sessions occurred between the hours of 9:00am and 8:00pm.

Prior to the start of each session, the experimenter referenced the pre-generated block-randomized order of participant numbers and corresponding conditions (see Appendix II for detailed randomization procedure). The condition-specific Qualtrics survey link was entered into an Incognito Google Chrome tab in full screen. Then the participant number was entered into the box on the first page. The participant number was never associated with any identifying information about the participant. The computer mouse was set parallel to the keyboard with the on-screen cursor set to the right of the first paragraph in the informed consent statement (see Appendix B). Additionally, a Caution Lab Testing in Progress sign was posted outside the testing room so that the sign could be seen by anyone that happened to pass through the hallway outside the testing room during testing. At two minutes prior to the start of the session, the experimenter—wearing a light blue lab coat from Red Kap—exited the testing room and walked to the lounge in Preston Hall, the location that participants had been instructed to wait for the

experimenter to greet them (Red Kap, 2021). The lab coat was worn as a way of standardizing experimenter clothing presentation to each participant.

The experimenter greeted each participant in the following format "[name]? You can follow me when you're ready" while both hands were in the pockets of the lab coat. When the participants got up to follow, the experimenter turned, removed their hands from the pockets of the lab coat, and took a right down the hallway toward the lab. After making a left at the end of the hallway and a left toward the testing room, the experimenter pushed the door open and turned around. If participants were holding a bag, the experimenter said, "You can leave your stuff in this corner if you would like" while pointing to the corner of the room to the left of the door upon entry. Then, the experimenter said "You may have a seat at the computer and begin when you're ready. And if you could set your phone to Do Not Disturb, that would be great." The experimenter walked to the couch perpendicular to the testing computer and sat down on the side furthest from the participant, beyond the field of vision while participants gazed at the computer. Upon sitting, the experimenter said, "I'll be seated here in case you have any questions at all." For the duration of the time the participant was reading, answering questions, playing Cyberball, and watching a Video, the experimenter was either reading or taking notes on their phone. The experimenter's phone was turned on Do Not Disturb mode and the sound was turned off. A phone was chosen over a computer due to the lack of keyboard noise. Additionally, the use of a phone by the experimenter during testing aimed to decrease the amount participants felt they were being watched. If participants verbalized any questions at any time, the experimenter verbally offered standard definitions of the terms or directions in question.

When the participants sat at the computer, they were met with an informed consent document which detailed the purpose of the document, an overview of their participation,

potential risks, benefits, compensation, confidentiality, and contacts that could provide more

information in the future. On the next screen, all participants chose "I consent" and continued to

the first set of pain measurements. Since pain experiences can vary greatly from individual to

individual, four pain scales were presented with the intention of capturing the specific pain

experience of each participant. In order, participants answered the Wong-Baker FACES Pain

Rating Scale (FACES), Need Threat Scale (NTS), Short-Form McGill Pain Questionnaire

(SF-MPQ), and Hurt Feelings Scale (HFS). These questionnaires can be found in Appendix D.

This first measurement period is referred to here as Baseline, since it is designed to account for

differences in pain between individuals prior to playing Cyberball.

      After answering the Baseline questions, participants were taken to a minimalist Cyberball

directions screen. Participants in the Pilot Exclusion condition were passed the ball three times

and then were excluded by the two onscreen players for the remainder of the approximately

three-minute gameplay period. Participants in the Pilot Inclusion condition were passed the ball

roughly one third of the time during the approximately three-minute gameplay period. Slight

variations in timing and passing percentages are due to individual choices to pass to either Player

2 or Player 3 and the time each individual takes to pass the ball once they receive it. The two sets

of gameplay parameters were customized through the Cyberball Configuration Builder, as

previously mentioned. After playing Cyberball, participants answered the same series of

questionnaires in what is referred to here as the Post-Cyberball measurement period.

      After answering the Post-Cyberball questions, participants were invited to watch the

previously-mentioned five-minute video. The purpose of this video was to occupy the

five-minute period that would be filled with a massage treatment during the later two phases of

this experiment, which are explained in more detail below. This video was chosen because it

meet the following criteria: 1) 4K footage; 2) no humans; 3) no man-made structures; 4) no animals; 5) subjectively beautiful footage. Since Cyberball relies on social cues, showing footage of nature without any evidence of social creatures—humans and other animals—was of paramount importance. The goal for this video was to occupy five minutes and not to influence feelings of social inclusion or exclusion. Additionally, since participants in the Experimental and Replication Conditions did not experience music at any time, the audio for the video was disabled. The video was presented through a YouTube link embedded into Qualtrics. The YouTube controls were hidden and the presentation of the Qualtrics continue button was delayed five minutes to ensure that participants did not continue before the video was complete. After the five minutes of video play was complete, an instruction to continue appeared. Upon continuing, participants answered the same series of questions a final time in what is referred to here as the Post-Video measurement period. A visual timeline overview of the in-lab flow of events can be found in Section 2 question 8 of Appendix I.

After answering the Post-Video questions, participants read a debriefing statement that included appreciations of their participation, explanations of all the possible conditions they could have experienced, justifications of the deceptions they may have experienced, and mental health resources should they have wanted additional support to cope with their experience (see Appendix E). Once participants were satisfied with their review of the document, they submitted the Qualtrics form. At this point, the experimenter stood up and said "Alright. Do you have any questions about the experiment?" What followed was an informal discussion of their experience, which was used in part to inform any changes that needed to be made before the next phase of the experiment and to get an idea of what participants may have experienced that may not have been captured by the questionnaires.

During this informal discussion, participants were asked to certify receipt of $15.00 for their participation by using a pen to write the date, the payment format, their name, and their signature. Again, this identifying information was never associated with the Qualtrics data and was only recorded for the purpose of keeping financial records for research spending audits.

Recruiting in-person participants has historically presented a challenge to researchers in the Psychology Department at Bard College. This challenge was expected to be heightened due to the COVID-19 pandemic guidelines which had ruled the lives of participants and researchers during the 20 months prior to the start of data collection here. Offering participants a higher rate of $15.00 per session was expected to increase the number of participants willing to leave their homes in the pursuit of participating in this lab. After participants exited the testing room, all surfaces used by participants during the experiment were wiped down with Clorox Fresh Scent Disinfecting Wipes (Clorox, 2015).

Pilot Phase Results and Discussion

Figure 2. Each of three plotted points represent average FACES pain ratings at one of three measurement periods for Pilot Phase participants who experienced Cyberball Inclusion (n.s. = not significant because $p > 0.05$; error bars represent adjusted marginal means).

As expected, there was not a significant change over time for Cyberball Inclusion. A

one-way repeated measures ANOVA confirms no reliable change in FACES pain score over time

from Baseline ($M = 1.10$, $SD = 1.53$) to Post-Cyberball ($M = 1.43$, $SD = 1.79$) to Post-Video (M

$= 0.96$, $SD = 1.61$), $F(0, 6) = 0.94$, $p = 0.42$ (see Figure 2). The bars in the above figure are 95%

confidence intervals with correction for between-subjects variability.
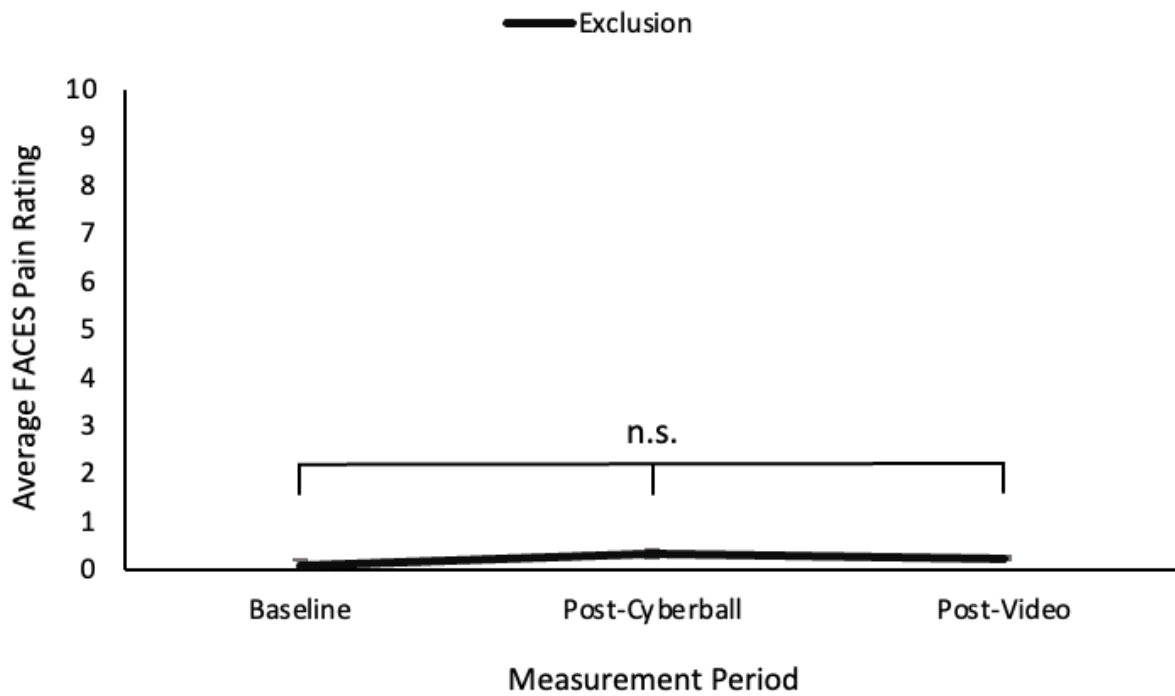
Figure 3. Each of three plotted points represent average FACES pain ratings at one of three
measurement periods for Pilot Phase participants who experienced Cyberball Exclusion (n.s. =
not significant because $p > 0.05$; error bars represent adjusted marginal means).

But, contrary to expectation, there was not a significant change over time for Cyberball

Exclusion. A one-way repeated measures ANOVA confirms no reliable change in FACES pain

score over time from Baseline ($M = 0.07$, $SD = 0.13$) to Post-Cyberball ($M = 0.34$, $SD = 0.74$) to

Post-Video ($M = 0.24$, $SD = 0.60$), $F(0, 6) = 0.78$, $p = 0.48$ (see Figure 3).

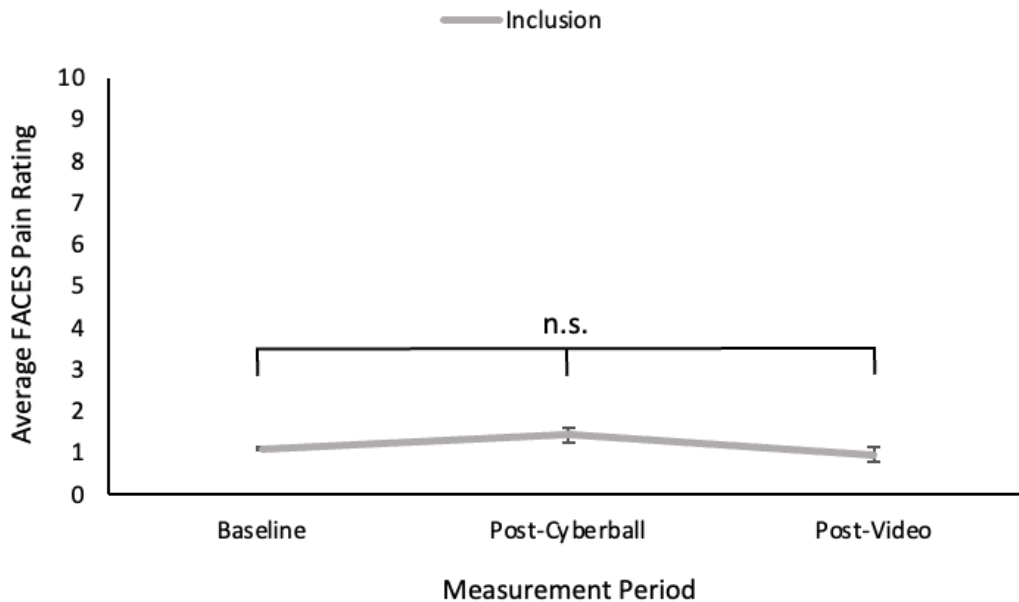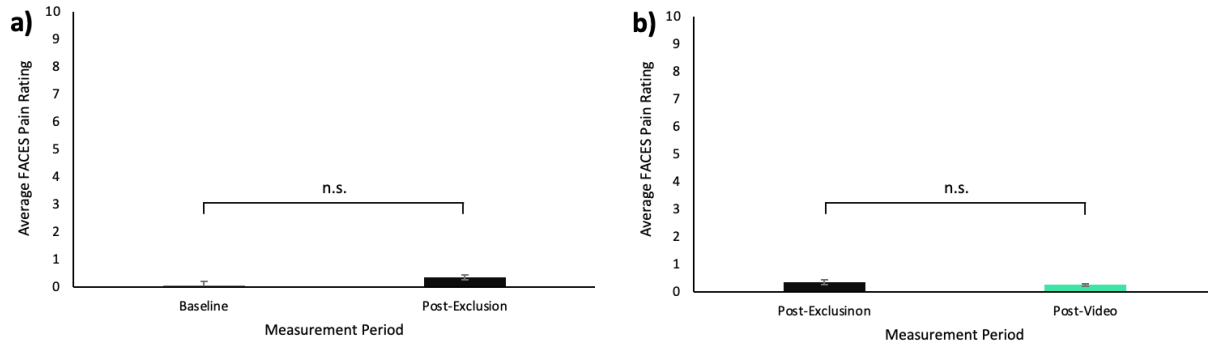*Figures 4a and 4b.* Each of two plotted points represent average FACES pan ratings at one of two measurement periods for Pilot Phase participants who experienced Cyberball Exclusion after Baseline (n.s. = not significant because $p > 0.05$; error bars represent adjusted marginal means).

A follow up, preregistered secondary t-test comparison confirmed that scores did not significantly increase from Baseline to Post-Cyberball from Cyberball Exclusion ($t[6] = -0.94$, $p = 0.19$; see Figure 4a) and did not significantly change from Post-Cyberball to Post-Video ($t[6] = 1.73$, $p = 0.13$; see Figure 4b).
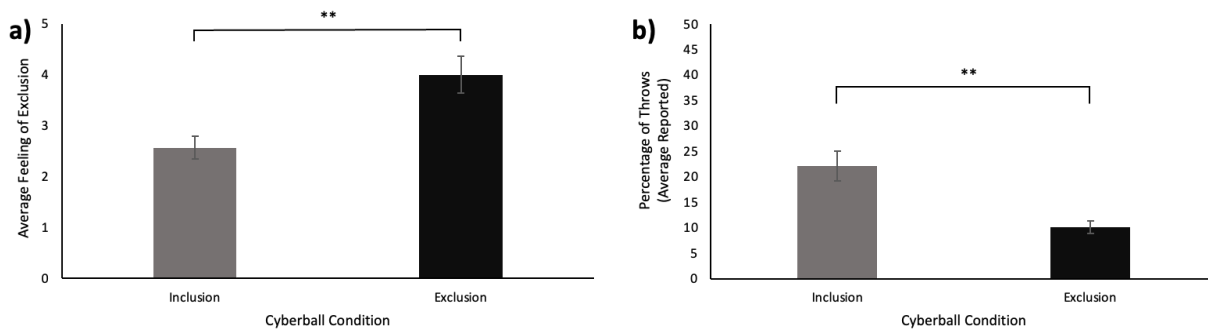
Figure 5a. Each of two plotted points represent average NTS items 29 and 30 ratings for Pilot Phase participants who experienced either Cyberball Inclusion or Cyberball Exclusion. *Figure 5b.* Each of two plotted points represent average NTS item 31 ratings for Pilot Phase participants who experienced either Cyberball Inclusion or Cyberball Exclusion. Note: ratings were out of 100%, not 50% as shown on the y-axis (** $p < 0.01$; error bars represent standard error).

The simplistic, preregistered manipulation check showed that participants reported a significant difference explicitly reported exclusion ($t[6] = -3.33$, $p = .006$; see Figure 5b) and reported a significant difference in the number of throws received ($t[6] = 3.81$, $p = .002$; see Figure 5b).

The purpose of the Pilot Phase was to replicate the widely-cited effects of Cyberball, validate the use of FACES as a repeated measure for pain induced by Cyberball, capture any deviations from the expected results, and identify any sources of confusion within the testing procedure. As expected, there was no significant change in the FACES pain score over time for participants who experienced Cyberball Inclusion (). Unexpectedly, there was also no significant change in the FACES pain score over time for participants who experienced Cyberball Exclusion. This lack of significant difference between measurement periods in the Cyberball Exclusion condition was confirmed with follow-up t-tests. These follow-up t-tests were only performed for the Cyberball Exclusion condition because this would be the primary condition of interest in the Experimental Phase. As evidenced by the finding that all mean scores fell under a score of one out of ten on FACES, the data suggests that the experimental procedure as a whole does not increase pain.

Given those findings, it is unclear whether Exclusion from Cyberball did not increase pain or that FACES does not capture the change in feelings caused by Exclusion from Cyberball. The manipulation checks provide support for the latter theory. The manipulation checks are built into the Need Threat Scale developed by Williams for use in Cyberball. Participants that experienced Cyberball Exclusion reported a higher average score of exclusion when asked how strongly they thought "I was ignored" and "I was excluded" during the game and reported a lower average perceived percentage of throws during the game. At the very least, this indicates that the game was programmed as intended and that participants were paying attention. But, given that this manipulation check is used in many experiments that report significant effects of Cyberball Exclusion in their other primary measures, it seems that the FACES scale did not capture the social pain induced by Cyberball Exclusion.

A review of the Cyberball literature had indicated that the effect of Cyberball was so robust that changes in variables, such as telling participants that the two other players were computers instead of humans or programming the two other players to be members of the participant's outgroup (the KKK), did not impact the ability for Cyberball to induce social pain. Because of this interpretation, a choice was initially made to minimize the deception to participants in this experiment. The directions were reduced to an indication that participants would play an interactive ball-tossing game whereby participants could pass the ball to the other players on screen by clicking on their names.

Based on informal behavioral observations of participants during the experimental procedure, conversations with participants after the experimental procedure, and analysis of participant data after the Pilot Phase, it became clear that during Cyberball gameplay, participants did not understand how to play the game and felt lost due to a lack of stated purpose, and that pain as measured by FACES did not increase after Cyberball Exclusion under these conditions of confusion (Williams, 2009).

Upon further review of the ability for the effects of Cyberball to generalize, one report speculated that an underlying story and general representation must either be portrayed by experimenters or endogenously created by participants. As seen here, simply watching and engaging with a minimal representation of Cyberball may not be enough to induce the commonly-reported effects of exclusion from a wide variety of Cyberball paradigms.

In order to address these concerns directly, a standard visualization cover story with explicit directions about gameplay with other online players that had names was added before the Experimental Phase (as described in the original Cyberball study by Williams et al., 2000). By

increasing the clarity and deception with which Cyberball was presented, it was hoped that Cyberball Exclusion would be an effective inducer of social pain for participants to follow.

Because Cyberball Exclusion failed to display its intended effect, the second goal of the Pilot Phase—to validate the use of FACES as a repeated measure for pain induced by Cyberball—could not be fulfilled. That is, it remained unclear whether an increase in pain due to Cyberball Exclusion would remain constant over the course of five minutes. Finding evidence of this test-retest validity would have strengthened explanations for any findings of change in pain from Post-Cyberball to Post-Treatment in the phases to follow. Unfortunately, the participant testing timeline did not allow for another Pilot Phase to be performed under the new conditions.

Experimental Phase

The Experimental Phase was designed to analyze whether the vibration from percussive therapy decreases the pain induced by Cyberball as compared to an active placebo. In order to clarify this concept, one primary hypothesis and four secondary confirmatory hypotheses were preregistered.

Experimental Phase Methodology

Experimental Phase Hypotheses and Planned Analyses

All the hypotheses and planned analyses listed in this methodology section were preregistered through the Open Science Foundation prior to Pilot Phase data collection (see Appendix II).

The primary hypothesis for the Experimental Phase was the main hypothesis of interest for the entire study—that vibration from percussive therapy would reduce the pain associated with Exclusion from Cyberball more readily than the Placebo. To test this hypothesis, a 2 x 2 mixed-factor analysis of covariance (ANCOVA) was performed. The covariate was the Baseline

FACES pain score. This controlled for individual differences in pain before playing Cyberball.

Each factor had two levels: treatment (Theragun or Placebo) and time (FACES pain score at

Post-Cyberball and Post-Treatment). A significant interaction of treatment and time would

indicate that a distinct pattern of change in pain scores could be attributed to the type of

treatment.

Four secondary comparisons were designed to localize the sources of difference within

the ANCOVA. First, it was expected that a between-participants t-test would show no difference

in pain scores at Baseline based on condition. Second, it was expected that another

between-participants t-test would show no difference in pain scores at the Post-Cyberball

measurement period because participants in both conditions experienced Exclusion from

Cyberball. Third, it was expected that another between-participants t-test would reveal decreased

pain scores for participants who received Theragun treatment as compared to the Placebo

treatment. Fourth, it was expected that a 2 x 2 mixed-factor ANOVA would reveal an increase

from Baseline to Post-Cyberball for all participants based on a main effect of time. Any analyses

beyond these five were exploratory in nature. Each analysis was reported below with in-text raw

descriptives and graphical visualization. Each graph includes a y-axis that represents the full

range of the scale and error bars that were calculated through adjusted marginal means to account

for the between-participant variabilities that were controlled for in the within-participant design,

unless otherwise noted (Cousineau, 2005).

Experimental Phase Procedural Evolution

17 participants were recruited for the Experimental Phase. An effect size of $f = 0.65$,

located within the range displayed by DeWall et al. (2010) and similar to the effect size reported

by Harterink et al. (2015), plus a conventionally-used power of 0.80 was adopted for the

Experimental Phase *a priori* analysis (Pataky et al., 2018). The calculations within G*Power resulted in an output that called for 16 participants (eight per condition) in the Experimental Phase (Faul et al., 2009). One participant was excluded from the final analyses, resulting in calculations with 16 participants.

The one excluded participant expressed discomfort during the vibration massage explanation by the experimenter prior to the treatment portion of the procedure. In accordance with preregistered exclusion criteria, the participant was thanked, given prorated compensation for their participation, removed from the final analysis list of participants, and immediately replaced with the next participant that arrived at the lab. The remainder of this section will describe only the aspects of the procedure that were different from the Pilot Phase. Since the Qualtrics files for all phases were submitted in the preregistration that locked before data collection began in the Pilot Phase, all these changes described in detail below are deviations from the initial plan that were deemed necessary by data and observations collected during the Pilot Phase (see the Qualtrics survey files link in Appendix III for the final versions used in the Experimental Phase).

During the Pilot Phase procedure, the experimenter noticed a high rate of initial confusion about the mechanics of the slider scale in the first FACES measurement. In order to increase comfort with this tool by the time participants reached that first important measurement, a practice section was added between the Informed Consent section and the Baseline measurement period. The practice section consisted of three slider scales with simple instructions, such as "Please drag the slider to 0 (leftmost value)."

During analysis of the Pilot Phase data, many participants bottomed out on many of the questions (i.e., many participants answered zero frequently). This and other low values makes

any analysis of change over time difficult or impossible. In an attempt to address this issue, participants were asked two additional practice questions whereby they were asked to report the level of sound that they currently hear. Other than a faint background buzz of electronics or the occasional passerby outside the lab, the lab was silent. For this reason, it was expected that many participants may be inclined to report zero or a very low number on the scale. When this question was presented on the next screen a second time to participants, the importance of careful consideration and use of the entire scale was highlighted as integral to the success of this experiment. If this caused participants to increase and finetune their focus, maybe their ratings on the later slider scales would better reflect their actual pain experience. In other words, it was hoped that participants who might be quick to answer zero out of a rounding bias due to lack of focus might be more sensitive to their actual experience in the pain questions to follow.

Minor formatting changes were made to all three FACES questions between the end of data collection for the Pilot Phase and the start of data collection for the Experimental Phase. First, the text margin was increased from 1500px to 1750px and the font size for the directions were decreased from 36px to 24px. Second, the continue button was shifted upward on the screen by changing its defaults to a padding of 20px and a margin-top of -75px. Additionally, the last three words in each of the NTS directions was bolded to draw attention to the reflection time period of interest. The referenced HTML code for these changes and the rest of the presentation is contained within the appended Qualtrics files (see Appendix III).

Because the Pilot Phase was unable to replicate the previously reported effect of Cyberball, more formidable changes were made to the presentation of Cyberball Exclusion, which all participants in the Experimental Phase experienced. The minimalist directions utilized in the Pilot Phase were based on a study that found these directions to not significantly impact

participants' feelings of social pain (Zadro et al., 2004). If this were true, deception seemed unjustified. Despite this single study, the standard in over 100 research studies that utilize Cyberball as part of their experimental procedure is to include a cover story that frames the game as a visualization task, when in reality, the experiment is concerned with participant reactions based on the number of times a ball is passed to them (as described in the original experimental procedure within Williams et al., 2000). Because inducing social pain is integral to testing the theory of pain outlined within, it was hoped that the addition of this relatively benign deception would help facilitate the purpose of the main experiments. Similarly, the onscreen player names were changed from Player 1, Player 2, and Player 3 to You, Jordan, and Sam. The use of You made it clearer for participants which player they were, an issue that was encountered during the Pilot Phase. Jordan and Sam were chosen as names to make the online aspect of the cover story more believable and because of their androgynous nature. An Amendment to the previously approved IRB Proposal was obtained to allow for this increase in deception used in the Cyberball directions. Additionally, the desired Cyberball settings were hosted through custom links created through the Cyberball 5 Windows application (Downing & Hales, 2020).

The final change from the Pilot Phase to the Experimental Phase was a preplanned one. Participants experienced one of two treatments—Theragun or Placebo—in place of the Video. When participants begin moving the computer cursor toward the continue arrow on the treatment instruction screen, visual confirmation that participants were ready to move on to the next step, the experimenter stood up, grabbed the Theragun with their left hand, took a couple steps toward the massage table, and said "Alright. You can empty your pockets and lay face down on this table here [experimenter placed right hand on massage table surface] with your head on this pillow [experimenter placed right hand on face pillow]." If participants had glasses, the

experimenter indicated that they could put their glasses on the table behind them. Some

participants asked if they had to take their shoes off. The experimenter allowed participants to do

whatever made them most comfortable. The massage table was an Oakworks Catalog #36639

(OakWorks Medical Products, 2021). An iNeckFit face pillow was arranged on top of a

cardboard box such that the top of the pillow was parallel with the surface of the table

(iNeckFitUSA, 2017). The cardboard box was covered with a red velvet Homebase window

curtain such that only the color red could be seen (Homebase, 2021).

Once participants were laying on the table, the experimenter slid the chair that

participants sat on while using the computer toward the couch to clear the walking path around

the table, held the Theragun to the left of each participant's head, and said "I will be using this

device to give you a vibration massage. I will spend 30 seconds on your left calf, 30 seconds on

your right calf, 30 seconds on your left hamstring, right hamstring, glutes, lower back, and upper

back." For participants in Placebo conditions, this additional line was verbalized between those

two sentences: "These vibrations occur above the average person's ability to consciously feel or

hear, though some participants report feeling rapid taps or warmth." Then, the experimenter

started a ten second countdown on their smartphone. At five seconds till the first 30 second

block, the experimenter said, "Turning the device on now... Here we go."

During Theragun application for participants in the Theragun condition, a Theragun Pro

with a Dampener attachment was applied perpendicularly to the body at 2400 percussions per

minute, the equivalent of 40 Hz, in the 'floating' or lightest force range (*Theragun PRO*, 2021).

The OLED display on the Theragun provided the experimenter with visual confirmation that

both of these criteria were being met by simultaneously displaying the number 2400 and zero of

six horizontal lines. More horizontal lines would have indicated that more force was being

applied. As an additional control of pressure, the experimenter used both hands to guide the Theragun, but did not lift the device up away from the body or push the device down toward the body while maintaining perpendicular contact of the dampener attachment with the body part of interest. In other words, the force applied was roughly equivalent to the weight of the Theragun, 2.9 lbs, at all times.

In each of the ten regions, the experimenter spent 30 seconds sweeping the designated area, with five second transitions between areas, for a total of six minutes. Time was kept with an interval timer on the experimenter's smartphone, outside each participant's gaze. A sweep is defined as a continuous motion that spans the entire length of the muscle belly without ever stopping in place. In order, the Theragun was applied to the following regions: 1) right calf (medial and lateral gastrocnemius); 2) left calf; 3) right hamstrings (biceps femoris and semitendinosus); 4) left hamstrings; 5) right glute (gluteus maximus); 6) left glute; 7) right lower back (latissimus dorsi); 8) left lower back; 9) right upper back (trapezius); 10) left upper back. These posterior locations were advantageous because they ensured that each participant remained blinded to the researcher's body language and facial expression during treatment. This was especially important because Cyberball—the chosen mechanism of pain induction—relied on social cues.

For the Placebo Condition, the only change to the massage procedure as described above was that the Theragun remained off. Between testing sessions, the Theragun battery used during testing was removed, placed on a charger, and replaced with the alternate, fully-charged battery to ensure that the battery level was consistent for all participants. Battery level was not expected to change the vibration intensity during the Theragun treatment, but was controlled anyway to ensure consistency.

Experimental Phase Results and Discussion
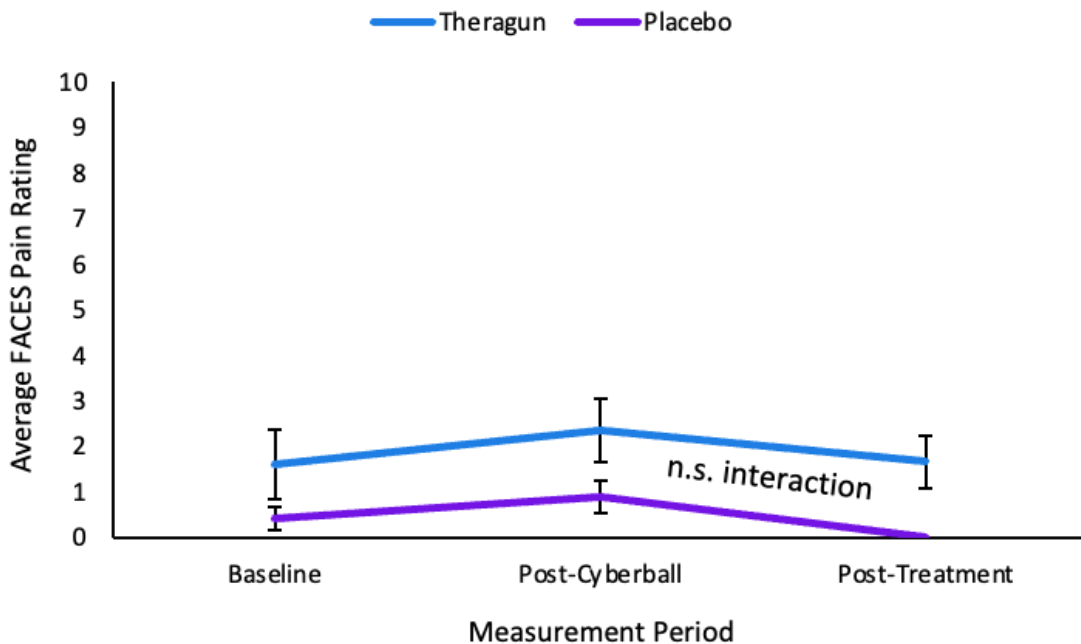
Figure 6. Each of six plotted points represent average FACES pain ratings at one of three measurement periods for Experimental Phase participants who experienced either Cyberball Inclusion or Cyberball Exclusion (n.s. = not significant because $p > 0.05$; error bars represent adjusted marginal means).

The primary planned comparison—a two by two mixed factor analysis of covariance (ANCOVA)—did not show the predicted significant interaction of treatment and time ($F[1,14] = 0.79$, $p = 0.39$; see Figure 6). In this comparison, the Baseline measurements acted as a covariate (so that individual differences in pre-existing pain could be controlled for). The interaction was a comparison of whether the within-subject differences between Post-Cyberball and Post-Treatment measurement periods differed based on Theragun or Placebo treatment. The results indicate a lack of support for the initial theory that the vibration from percussive therapy would decrease the pain from Cyberball Exclusion at a higher rate than the active Placebo treatment.

Figure 7. Each of two plotted points represent average FACES pain ratings for Experimental Phase participants in either Theragun or Placebo condition at the Baseline measurement period (n.s. = not significant because $p > 0.05$; error bars represent adjusted marginal means).

Though the primary analysis did not yield the expected primary analysis result, its visualization inspired alternative theories about what these participants might have experienced instead. For one, it appeared that the average Baseline pain between the Theragun ($M = 1.61$, *SD* $= 2.18$) and Placebo ($M = 0.43$, $SD = 0.72$) conditions were different. A preregistered secondary confirmatory t-test showed that though this difference was apparent, it was not statistically significant ($t[15] = 1.46$, $p = 0.17$; see Figure 7). It should be noted that this and all statistical analyses reported here are performed with relatively small sample sizes. Therefore, even in accordance with *a priori* statistical justification, they are subject to the same limitations of any small samples, such as the potentially strong influence of individual participants on the entire dataset and limitations to generalizability.

Figure 8. Each of two plotted points represent average FACES pain ratings for Experimental Phase participants in either Theragun or Placebo condition at the Post-Cyberball measurement period (n.s. = not significant because $p > 0.05$; error bars represent adjusted marginal means).

Additionally, as expected, another preregistered secondary confirmatory t-test showed that the Theragun ($M = 2.35$, $M = 1.96$) and Placebo ($M = 0.9$, $SD = 1.02$) conditions resulted in a non-significant difference at the Post-Cyberball measurement ($t[15] = 1.85$, $p = 0.085$; see Figure 8). By some statistical standards, though not the one preregistered here, this difference could be considered marginally significant. What remains important here is that participants who experience Cyberball Exclusion report an increase in pain on FACES.

Figure 9a. Each of four plotted points represent average FACES pain ratings for Experimental Phase participants in either Theragun or Placebo condition at one of two measurement periods.

Figure 9b. Each of two plotted points represent average FACES pan ratings for all Experimental Phase participants at one of two measurement periods (n.s. = not significant because $p > 0.05$; * p < 0.05; error bars represent adjusted marginal means).

The preregistered secondary confirmatory analysis of variance (ANOVA) was included to get at this point. This test showed that there was not a statistically significant change from the Baseline to Post-Cyberball measurements based on the factor of time ($F[1,14] = 4.24$, $p = 0.059$; see Figure 9a). As referenced earlier, this result falls above the statistical significance cutoff that was preregistered by a margin of .009. Without a reliably reported increase in pain, it would both be difficult to determine whether any treatment could decrease this pain and it would be difficult to justify the use of Cyberball as presented here in conjunction with FACES for the Replication Phase to follow. Because of the importance of this finding, an exploratory paired samples t-test was added to analyze the change in pain ratings from Baseline ($M = 1.02$, $SD = 1.68$) to Post-Cyberball ($M = 1.63$, $SD = 1.69$) another way with scores from participants in both conditions combined. The results were significant and found the effect of Cyberball Exclusion to be medium ($t[15] = -2.12$, $p = 0.026$, $d = -0.529$; see Figure 9b). While ANOVAs are generally thought of to be more powerful than t-tests with more than two variables, the t-test design in this case was able to specify the expected directionality (i.e., that the Post-Cyberball pain rating would be higher than Baseline). Without this specification, the result was nearly the same as the ANOVA output without the between-subjects factor: $p = 0.051$. When the expected directionality was selected, however, the difference was indeed shown to be significant. Taken together, the evidence shows that Cyberball increased pain, as captured by FACES, and that this paradigm should be maintained for the Replication Phase.
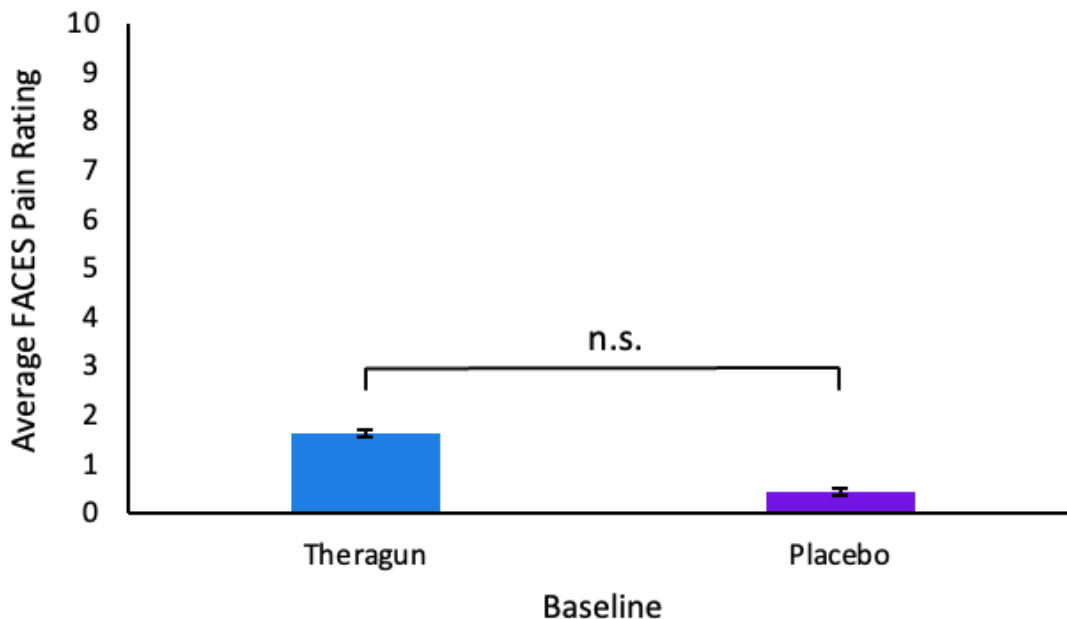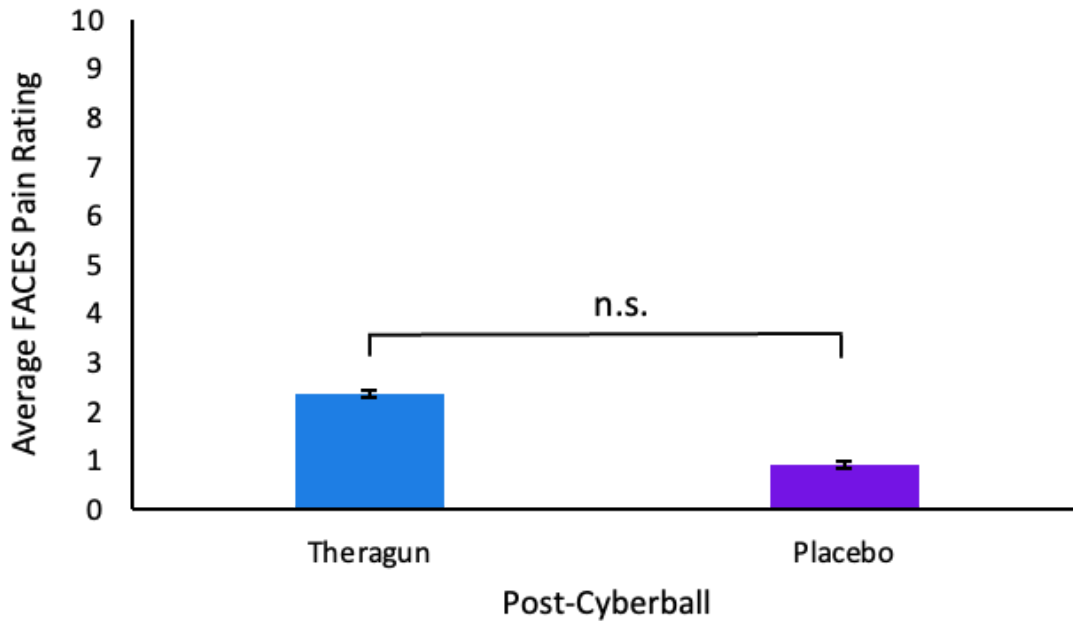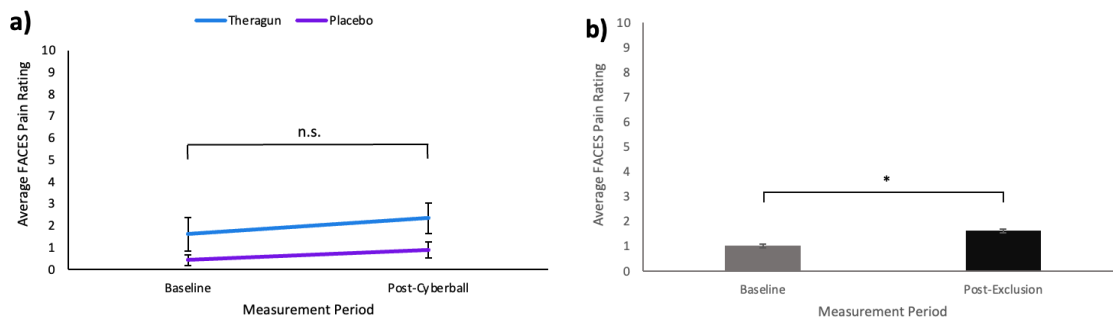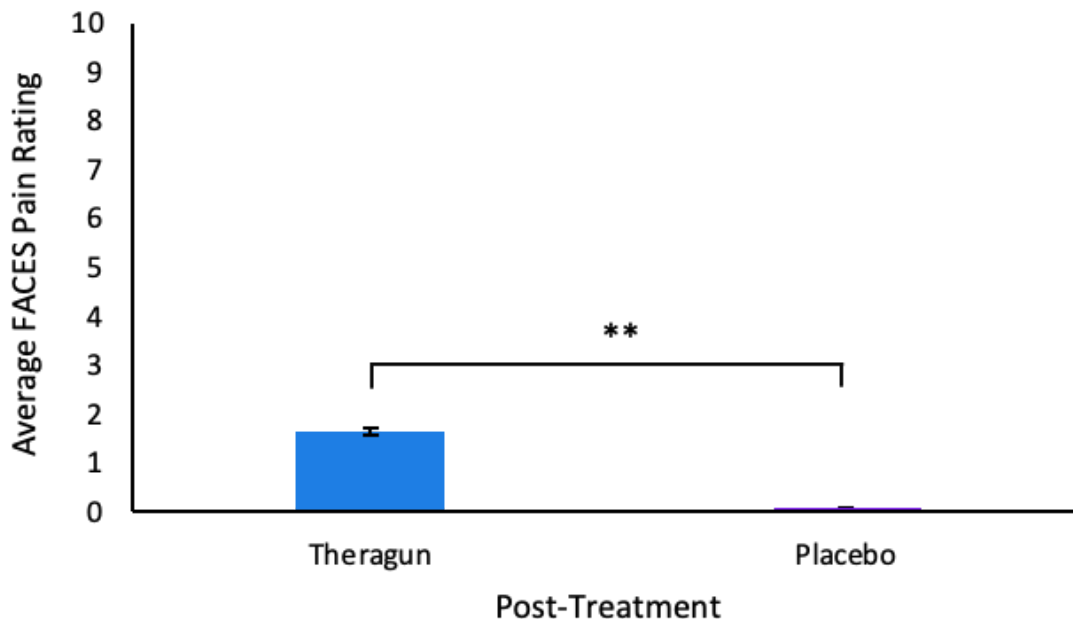
Figure 10. Each of two plotted points represent average FACES pain ratings for Experimental Phase participants in either Theragun or Placebo condition at the Post-Treatment measurement period (** $p < 0.01$; error bars represent adjusted marginal means).

The last preregistered secondary analysis was designed to confirm that there was a difference at the Post-Treatment measurement period between conditions, had the interaction of time and treatment been significant. As mentioned earlier, this interaction was not significant, and this secondary analysis instead shows that the difference in Theagun ($M = 1.66$, $SD = 1.64$) and Placebo ($M = 0.01$, $SD = 0.04$) conditions was significant in the opposite direction ($t[15] = 2.85$, $p = 0.006$, $d = 1.43$; see Figure 10). This significant difference based on treatment condition at the Post-Treatment pain ratings is at odds with the non-significant confirmatory t-test performed between treatment conditions at Baseline ratings plus the non-significant interaction of time and treatment. If the Placebo caused participants to lower their pain scores more than the Theragun treatment, the interaction would have been significant. So when all three pieces of evidence are taken together, it seems instead that this difference at the Post-Treatment

measurement was actually due to differences at Baseline, which, stated again, were not

statistically significantly different.
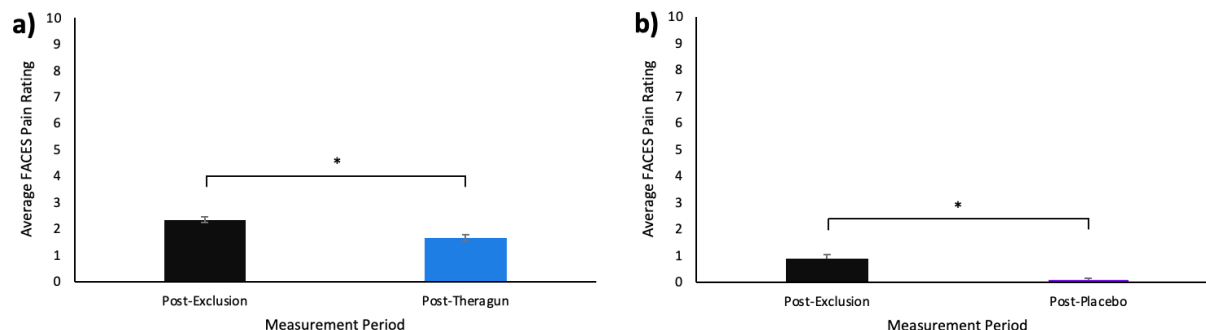
Figures 11a. Each of two plotted points represent average FACES pain ratings at one of two measurement periods for Experimental Phase participants in the Theragun condition. *11b*. Each of two plotted points represent average FACES pain ratings at one of two measurement periods for Experimental Phase participants in the Placebo condition. (* $p < 0.05$; error bars represent adjusted marginal means).

Because of this confusion, two exploratory analyses were performed to see whether the

decrease in each condition between the Post-Cyberball and Post-Treatment measurements was

significant. The first of these exploratory analyses found that participants in the Theragun

condition experienced a statistically significant decrease in pain scores from Post-Exclusion to

Post-Theragun treatment ($t[7] = 2.12$, $p = 0.036$, $d = 0.75$; see Figure 11a). This finding aligns

with the hypothesis that the vibration from percusive therapy would decrease the pain induced

by Cyberball. But the second of these exploratory analyses also found that participants in the

Placebo condition experienced a statistically significant decrease in pain scores from

Post-Exclusion to Post-Placebo treatment ($t[7] = 2.42$, $p = 0.023$, $d = 0.86$; see Figure 11b). This

finding calls into question what exactly has caused this decrease in pain and further justifies the

importance of collecting more data in the Replication Phase. It also supports the stance that the

significant difference between conditions reported at the Post-Treatment measurement were,

indeed, due to differences in starting point. Further speculative discussion here is reserved until the Replication Phase data has been added to the conversation.

<div align="center">**Replication Phase**</div>

The goal of the Replication Phase is to expand upon the findings from the Experimental Phase through the addition of more participants in the two Cyberball Exclusion conditions and to extend the two treatment conditions to participants who have experienced Cyberball Inclusion (i.e., not experienced experimentally-elevated levels of pain). To focus the studies within these four conditions, one primary hypothesis and four secondary confirmatory hypotheses were preregistered.

Replication Phase Methodology

Replication Phase Hypotheses and Planned Analyses

The primary hypothesis for the Replication Phase was that pain scores for participants would differ at the Post-Cyberball and Post-Treatment measurements due to a three-way interaction between Cyberball, treatment, and time. A 2 x 2 x 2 mixed-factor ANCOVA was performed to test this hypothesis. The covariate was the Baseline FACES pain score. Each factor had two levels: Cyberball (Inclusion or Exclusion), treatment (Theragun or Placebo), and time (FACES pain scores at Post-Cyberball and Post-Treatment). A significant interaction of Cyberball, treatment, and time would indicate that a distinct pattern of change in pain scores could be attributed to the type of treatment and the Cyberball condition.

Four secondary comparisons were designed to localize the sources of difference within the ANCOVA. All secondary comparisons were performed with 2 x 2 ANOVAs. In relation to the 2 x 2 x 2 ANCOVA described above, the 2 x 2 ANOVAs were designed to remove the factor of time. In other words, these were comparisons of all four conditions at a single time point.

First, it was expected that a 2 x 2 ANOVA for all participants would show no difference at Baseline based on condition. Second, it was expected that another 2 x 2 ANOVA would reveal a main effect of Cyberball with no reliable interaction at the Post-Cyberball measurement, such that participants who experienced Exclusion from Cyberball would report higher levels of pain than participants who experienced Inclusion from Cyberball. The third preregistered secondary comparison was an accidental repetition of the second comparison, and will therefore be ignored for the purposes of reporting the results of all preregistered analyses. Fourth, it was expected that another 2 x 2 ANOVA would reveal an interaction of Cyberball and treatment at the Post-Treatment measurement.

Any analyses beyond these five were exploratory in nature. Each analysis includes raw descriptives in text and is accompanied with a graphical visualization of the results. Each graph includes a y-axis that represents the full range of the FACES scale and error bars that were calculated through adjusted marginal means to account for the between-participant variabilities that were controlled for in the within-participant design, unless otherwise noted (Cousineau, 2005).

Replication Phase Procedural Evolution

Two conditions, in addition to the two Conditions from the Experimental Phase, were added in the Replication Phase. The four resulting conditions were Exclusion Theragun, Exclusion Placebo, Inclusion Theragun, and Inclusion Placebo. The Cyberball Exclusion and Inclusion settings were the same as described in the Experimental Methodology section. The Theragun and Placebo procedures were also the same as described in the Experimental Methodology section. And the same parameters justified in the Experimental Phase Methodology (effect size of $f = 0.65$ and a power of 0.80) called for 24 participants (six per condition) in the

Replication Phase. Data was collected for 26 participants. One participant's data was excluded and one participant was added after an extension to the randomization procedure described in detail within Appendix II.

The one excluded participant expressed discomfort during the vibration massage procedure. Upon beginning stimulation of the left glute, the participant vocalized a request to skip this region. The experimenter allowed the participant to finish the rest of the procedure and paid the participant for their participation. After data collection was complete, it was determined that skipping treatment for both glutes qualified as not completing the entire experimental procedure. In accordance with the preregistered data exclusion criteria described in Appendix II, any participant who does not complete the entire procedure must be excluded from the final data analysis. Deliberation about whether or not this meets the exclusion criteria caused a delay in replacing this participant with the next participant that arrived to the lab. For this reason, the 25th participant of the phase replaced the 6th participant. If the decision were made before the next participant arrived, as was intended at preregistration, the 7th participant would have replaced the 6th participant.

Very minor formatting changes were made to further optimize the visual presentation of all three FACES questions. First, the font size of the directions was increased from 24px to 30px. Second, the continue button was shifted upward on the screen by changing the margin-top from -75px to -125px. These formatting alterations should be noted as deviations from the preregistration because they were not included in the Qualtrics files submitted prior to the collection of data for the Pilot Phase. The originally submitted questionnaires can be found at the preregistration files link in Appendix III. The referenced final HTML code and the rest of the

presentation is contained within at Qualtrics survey files link in Appendix III. The remainder of

the Qualtrics questionnaire was the same as presented in the Experimental Methodology section.

Replication Phase Results and Discussion

Figure 12. Each of twelve plotted points represent average FACES pain ratings at one of three measurement periods for Replication Phase participants who were in one of four conditions. Note: the FACES scale ranges from zero to ten. The y-axis range is reduced here to make the complexities of this graph more visible (error bars represent adjusted marginal means).

The primary comparison for the Replication Phase is a 2 x 2 x 2 mixed-factor ANCOVA.

The three factors each have two levels: Cyberball (Inclusion, Exclusion), treatment (Theragun,

Placebo), time (FACES pain score at Post-Cyberball and Post-Treatment). The hypothesized

three way interaction between Cyberball, treatment, and time was not statistically significant

($F[3, 20] = 1.94$, $p = 0.179$; see Figure 12). Follow up, preregistered secondary analyses were

performed to gain a better understanding of the dynamics between these factors.
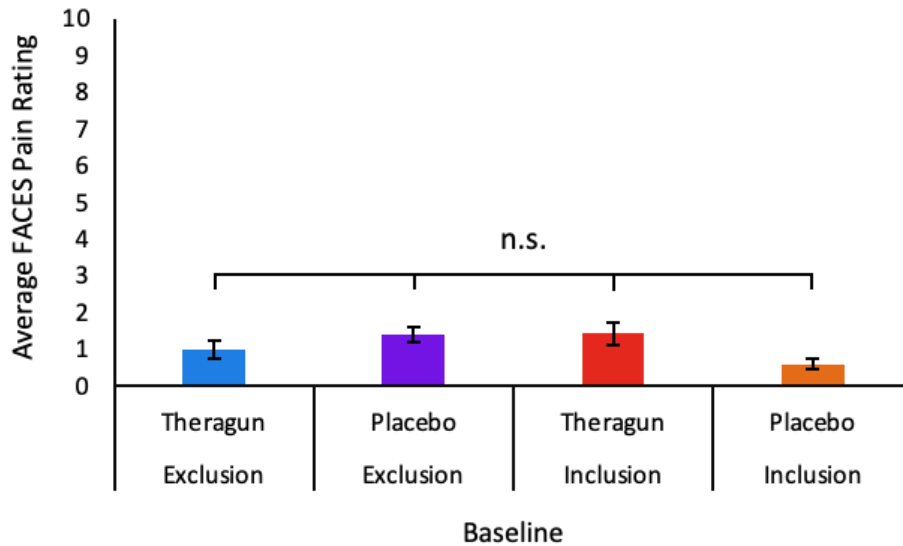
Figure 13. Each of four plotted points represent average FACES pain ratings for Replication Phase participants in one of four conditions at the Baseline measurement period (n.s. = not significant because $p > 0.05$; error bars represent adjusted marginal means).

As expected, the first secondary confirmatory analysis showed no significant difference between conditions at the Baseline measurement ($F[3, 20] = 1.20$, $p = 0.286$; see Figure 13). That is, participants did not arrive at the lab with differing levels of pain.
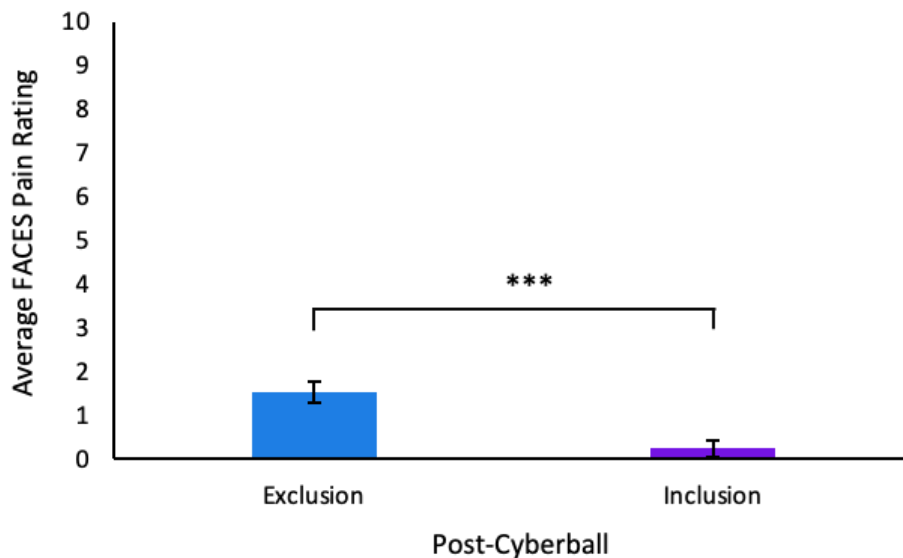
Figure 14. Each of two plotted points represent average FACES pain ratings at the Post-Cyberball measurement period for Replication Phase participants who experienced either Cyberball Exclusion or Cyberball Inclusion (*** $p < 0.001$; error bars represent adjusted marginal means).

As expected, the second secondary confirmatory analysis showed a significant main effect of Cyberball at the Post-Cyberball measurement such that participants who experienced Exclusion from Cyberball reported higher levels of pain than participants who experienced Inclusion from Cyberball ($F[3,20] = 20.82$, $p < 0.001$; see Figure 14).
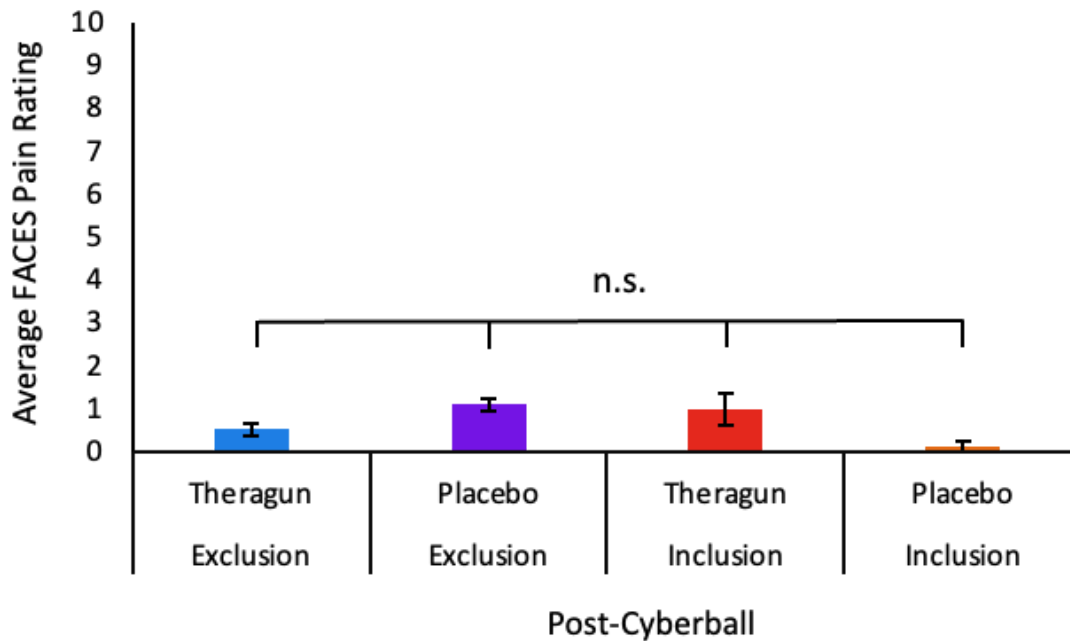
Figure 15. Each of four plotted points represent average FACES pain ratings for Replication Phase participants in one of four conditions at the Post-Cyberball measurement period (n.s. = not significant because $p > 0.05$; error bars represent adjusted marginal means).

Unexpectedly, the third secondary confirmatory analysis did not show a significant interaction between Cyberball and treatment ($F[3, 20] = 2.74$, $p = 0.113$; see Figure 15). After these preregistered primary and secondary analyses were performed, it remained unclear whether there were statistical changes from Post-Cyberball to Post-Treatment within each specific condition.
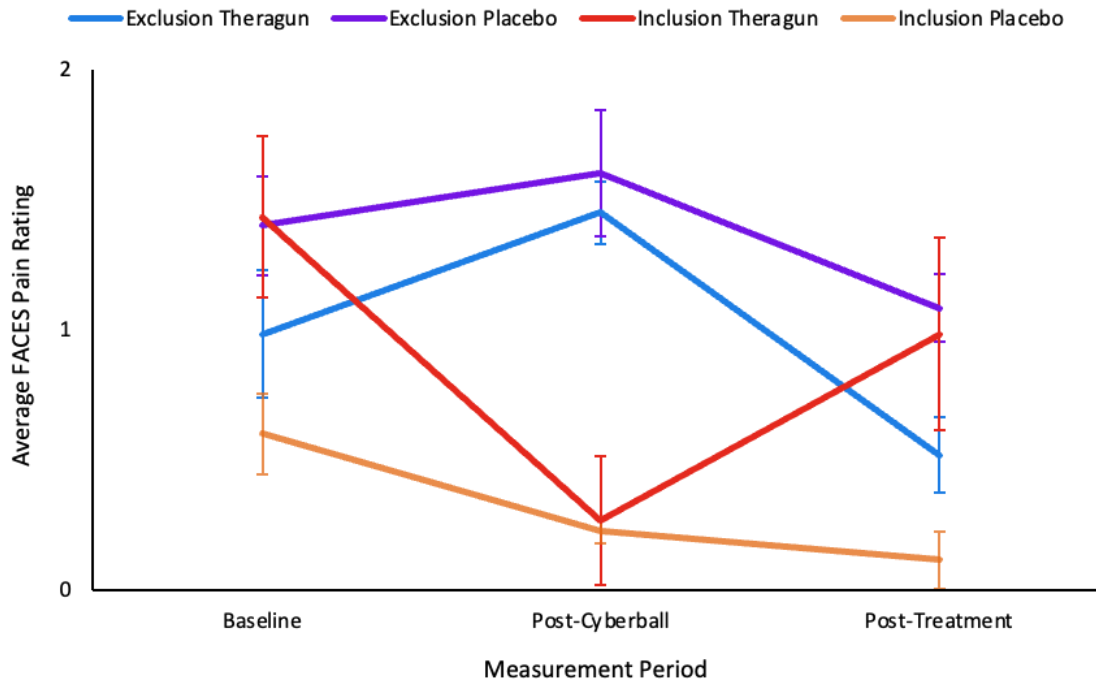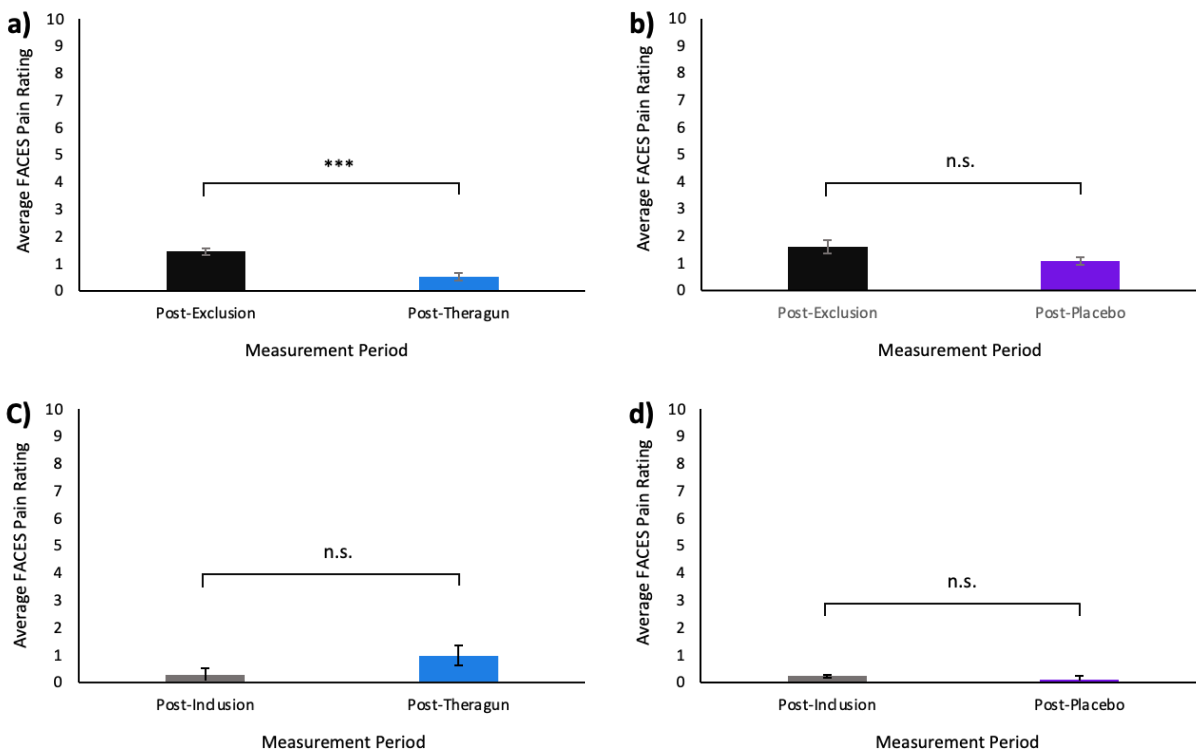
Figures 16a, 16b, 16c, and 16d. Each of two plotted points represent average FACES pain ratings at the second or third measurement period for Replication Phase participants in one of four conditions (n.s. = not significant because $p > 0.05$; * $p < 0.05$; error bars represent adjusted marginal means).

Using the data collected within the Replication Phase, four exploratory paired samples t-tests indicated a significant difference in pain ratings in only one of the four groups of participants—those who experienced Cyberball Exclusion and received the Theragun treatment ($t[5] = 7.43$, $p > 0.001$, $d = 3.03$; see figure 16a). The slight visual decrease between Post-Cyberball and Post-Treatment measurements for participants who experienced Cyberball Exclusion and received the Placebo treatment ($t[5] = 1.23$, $p = 0.274$, $d = 0.50$; see Figure 16b), visual decrease for participants who experienced Cyberball Inclusion and received the Placebo treatment ($t[6] = 1.49$, $p = 0.188$, $d = 0.56$; see Figure 16d), and visual increase for participants who experienced Cyberball Inclusion and received the Theragun treatment ($t[5] = -1.04$, $p = 0.345$, $d = -0.426$; see Figure 16c) all resulted in non-significant outputs. It should be noted that

these analyses were performed with a low number of participants per group, so all patterns should not be considered absolute.
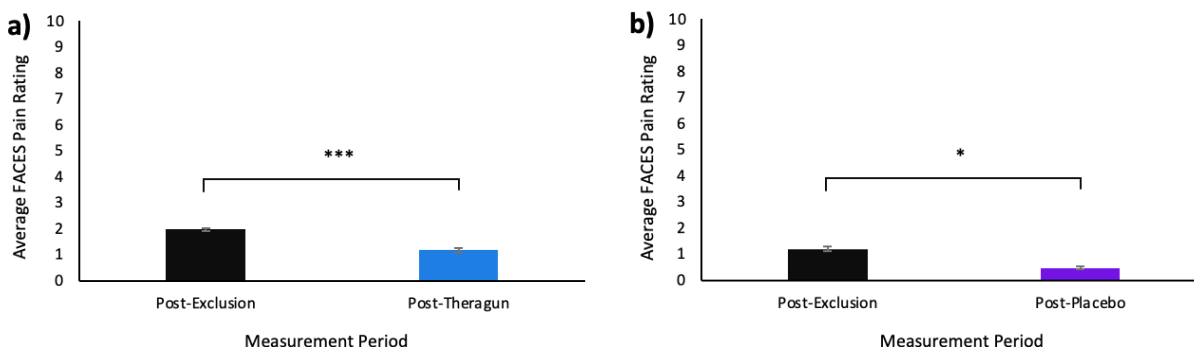
Figures 17a and 17b. Each of two plotted points represent average FACES pain ratings at the second or third measurement period for Experimental and Replication Phase participants that experienced Exclusion from Cyberball and either Theragun or Placebo treatment (* $p < 0.05$; *** $p < 0.001$; error bars represent adjusted marginal means).

The first two additional exploratory paired samples t-tests were then repeated and strengthened by combining data from participants in the two overlapping conditions within the Experimental Phase and Replication Phase. The first exploratory analysis in this series strengthened the finding that participants who experienced Cyberball Exclusion and received the Theragun treatment reported a decrease in pain from the Post-Cyberball measurement ($M = 1.96$) to the Post-Treatment measurement ($M = 1.17$; $t[13] = 4.18$, $p > 0.001$, $d = 1.12$; see Figure 17a). The second exploratory analysis in this series showed a significant decrease in pain from the Post-Cyberball measurement ($M = 1.20$) to the Post-Treatment measurement ($M = 0.47$) for participants who experienced Cyberball Exclusion and received the Placebo treatment ($t[13] = 2.69$, $p = 0.018$, $d = 0.72$; see Figure 17b). This second finding contradicted the complementary exploratory analysis performed with only data from the Replication Phase. Because the experimental procedure was the same for participants in both phases, the second analysis with more data points will be interpreted in place of the first finding. Findings from all three phases are put into conversation with each other in the General Discussion that follows.

General Discussion

By way of summary for the experimental portion of this project, the Pilot Phase resulted in a failure to replicate the widely-cited Cyberball effects within the lab setting of this study (Hartgerink et al., 2015). This informed a crucial Cyberball redesign that successfully replicated these effects in the Experimental and Replication Phases. The Experimental Phase provided initial evidence that the pain from Cyberball Exclusion decreases in participants who experienced both Theragun treatment and its active Placebo treatment. This finding was strengthened through the addition of data collected in the two overlapping conditions of the Replication Phase. The two new conditions introduced in the Replication Phase showed that both treatments did not impact the low average levels of pain reported by participants who experienced Cyberball Inclusion. Even if the statistical interpretations of this data from a small, college-aged sample are taken to be true across the large, diverse human population, a number of questions remain as to the specific mechanism or mechanisms through which these effects might occur. The following section explores the major considerations in this discussion.

It was hypothesized that the Theagun treatment would reduce pain over and above any change in pain that was caused by the placebo treatment due to the neurological and physiological mechanisms triggered by vibration. Instead, the data suggests that treatment from both Theragun and its active Placebo reduce pain similarly. Importantly, these two conditions were designed to isolate the variable of vibration delivered at a frequency of 40 Hz and an amplitude of 16 mm. Had there been a significant difference in pain modulation between the two conditions, the effect could have reasonably been attributed to vibration. Since there was pain modulation, and that pain modulation did not differ between conditions, the discussion must be

opened up to the broader category of all the characteristics that these two conditions share and speculation about which of these similarities caused the decrease in pain.

Percussive therapy defines a wide variety of combined applications of pressure and vibration. The design of percussive therapy devices allow users and practitioners to apply a wide range of pressure (Roberts, 2020). The pressure used in this experiment was on the low end of the scale, in what is commonly referred to as 'floating.' Both treatment conditions utilized this floating technique. Support for this as the mechanism through which pain was decreased comes from hypotheses that this floating technique is relaxing and improves sleep (Biostrap, 2020; Therabody, 2020). Additional support comes from reports of pain reduction through forms of manual massage that utilize light amounts of force over wide areas of muscle Miake-Lye et al., 2019).

Both treatment conditions also shared an aspect of attention paid by the practitioner. Given the nature of the experimental pain induction method utilized here—social exclusion—special consideration was taken in the design of the experimental procedure to minimize the social interactions between the experimenter and the participants in order to minimize any uncontrolled social variables that might impact the primary measure. Specifically, in the time between social exclusion from Cyberball and the Post-Treatment measurement period, participants were asked a series of questions to capture their pain experience and given instructions about their treatment through the standardized Qualtrics text displayed on the computer screen in the lab (see Qualtrics survey files in Appendix III for a full display of these directions). When the participants stood up to move to the massage table, the experimenter only confirmed where they should mount the table, what not to bring with them (e.g., glasses or anything in their pockets), and repeated the nature of their massage to minimize any surprise that

might have otherwise occurred during the massage. Furthermore, the massage procedure was designed such that participants lay on the ventral surface of their body with their faces inside a pillow that occluded their vision past the red surface that supported the pillow. The treatment was applied to the dorsal surfaces of their body so that participants would not be influenced in any way by the experimenter's body language or facial expressions, which were further hidden behind a surgical mask due to college-mandated health protocols at the time of testing. Even with all these precautions, five minutes of treatment applied by an experimenter to a participant may have been enough attention to counteract the pain induced by social exclusion.

The decrease in both pain from both treatment conditions could have been to the placebo effect (Colloca, 2019). That is, a pre-existing cognition that this treatment would make participants feel better could have made them feel better. This cognition would have had to be pre-existing because there was no explicit explanation that this treatment would make participants feel better. Furthermore, there was no explanation of what was being measured or that there was any expectation of change of any kind over the course of the experiment. In fact, the treatment was referred to as a "vibration massage" in order to remove any associations with prior knowledge of percussive therapy, the more common title for the modality, or any other kind of therapy. One could raise the argument that the large number of questions referring to "pain" could have made participants susceptible to knowledge of the outcome variable of interest and consequently changed their answers due to a demand effect (McDonald & Weiskopf, 2001). But if this argument were true, it would likely follow that participants who experienced Inclusion from Cyberball also would have changed or decreased their pain scores over time, which was not the case.

In the case of physical treatment modalities, such as manual massages, health practitioners may explicitly explain the intended effects of their treatment, offer treatment in response to an explicit request or complaint such that the implicit intended effect is to reverse the complaint, and generally are relied upon as knowledge authorities in their area of expertise. Participants may have reacted similarly toward experimenters to the extent that the experimenter was wearing a lab coat and presumably contained knowledge about the experiment that participants did not have. The only confirmation along this line of thinking occurred when the experimenter positioned themselves to "answer any questions you [the participant] may have" at the beginning of the experimental procedure. But such answers and interactions were designed to be definitional and procedural in nature so as to minimize expectations imparted upon participants until the debriefing that occurred after the entire experimental procedure was complete.

There is also the possibility that the time it took to execute the treatments was enough by its own accord to reduce the pain from Cyberball Exclusion. The Pilot Phase aimed to address this question by measuring pain immediately Post-Exclusion and again after a five-minute video, designed as a placeholder for what would later be either of the two treatments. Unfortunately, the failure to induce pain from Cyberball Exclusion made detecting the extent to which the effect of Cyberball Exclusion lasts over this time period impossible. Previous studies cite an effect of up to 45 minutes in participants with high anxiety and a detectable brain imaging change on the order of roughly five to ten minutes. In each of those cases, pain was quantified with fMRI. On the other hand, Williams argues that self-reported reflexive pain responses, such as those targeted with his Need Threat Scale, must occur immediately following Cyberball (Hartgerink et al., 2015). The primary measure in this experiment was the FACES pain scale and the conditions of

each lab and procedure are slightly different. Thus, it remains unclear exactly how long this effect would last in this particular lab setting with this particular pain measure.

Additionally, if increased pain had been shown after Cyberball Exclusion at the Post-Cyberball and Post-Video measurement periods on the FACES pain scale, it would have been clear that the FACES pain scale had good test-retest reliability for this specific use case. FACES has a history of pre-/post-testing and even continuous measurement of pain outcomes in clinical and experimental settings for physical pain, but, again, the failed Pilot Phase manipulation limits the ability to validate this scale with a high level of certainty (Williams, 2009). It could be, for example, that social pain is lost with repeated use of this particular scale while physical pain is not.

It could also be the case that the increase in pain reported by participants who experienced Exclusion from Cyberball was not large enough to reliably detect the difference in treatment between Theragun and the Placebo conditions. Future designs may benefit from the use of more recently developed virtual reality platforms to administer more realistic versions of the Cyberball Exclusion paradigm through the inclusion of signals from body language, facial expressions, eye contact, and other non-verbal means of communication that are lost in the popular Cyberball design (Kassner et al., 2012). If these newer paradigms are able to increase pain levels more than the version used in this experiment, studies of pain modulation with vibration and percussive therapy may be able to detect smaller effects.

Continuing along the line of statistical power, the nature of the sample recruited for this study could have resulted in a statistical anomaly. The planned sample size was not designed to reliably detect small or medium effect sizes. And even large effect sizes could have been reported as significant or non-significant due to chance alone. A replication of this study with

more participants from a more diverse population than those recruited at Bard College may yield

different results.

As with the early stages of any scientific pursuit, it is clear that many open questions

remain regarding the relationship between percussive therapy and pain. 1) What percussive

therapy settings are most conducive to pain reduction? Settings include vibration frequency,

vibration amplitude, treatment surface (i.e., percussive therapy attachment material), timing of

treatment in relation to the pain stimulus, location of treatment in relation to the pain stimulus,

duration of treatment, and application of treatment by the self or another. 2) What types of pain

are most conducive to pain reduction by percussive therapy? Examples include the types of pain

induction mentioned in the Experimental Models of Physical Pain and the Experimental Models

of Social Pain and any category of pain one might experience in the real world, be it chronic or

acute in nature. 3) What personality or health predispositions are most sensitive to the positive

and negative effects of percussive therapy? 4) What precise neurological and physiological

mechanisms does each component of percussive therapy engage? Robust methodological

research designs are needed to further clarify these complex relationships. Such clarification is

necessary to reach a state of confidence whereby evidence-based recommendations can help

guide health practitioners toward the most effective percussive therapy protocols for pain

reduction. Given the widespread prevalence of pain, plus the accessibility of percussive therapy

as a treatment and its relative ease of application, a deep understanding of these dynamics may

provide the opportunity to improve the quality of life for many.

In the face of so many open questions, the development of a comprehensive percussive

therapy literature for pain modulation and other applications should learn from the mistakes

made in wider massage literature. If clear guidelines are to be made, research with rigorous

standardizations of each variable within the term percussive therapy ought to be defined and executed in a systematic way. In order to reach systemization, a series of long-term research pipeline planning sessions with input from all stakeholders—customers, researchers, practitioners, manufacturers, policymakers, and practitioners—with a diverse set of voices must occur first. Without a systematized approach, specific findings in specific conditions talk past each other (Ghazi et al., 2021). This is a waste of resources including time, money, and brainpower that could be put to use toward something with meaning, something that could build a greater understanding of useful, generalizable principles for the improvement of life quality for all.

As a general framework for this approach, researchers in this and any field might seek inspiration from the scale of NASA Technology Readiness Levels, as applied to the behavioural sciences in the context of decisions that relate to COVID-19 (IJzerman et al., 2020). To reach high enough levels of organization, systemazation, and confidence to send human-carrying technology into space or to justifiably apply behavior change policy during a global health crisis, massive amounts of resources are required. So, if it is the case that percussive therapy "just works" for all or that the potential benefit from the modality or risk from a lack of understanding is not large enough, then maybe such an investment would be better served elsewhere. Or maybe the conditions are such that the investment is worth the potential return that would result from a strengthened body of knowledge. Either way, a hierarchical meta-ranking system of areas of study must be discussed and debated. It is difficult to predict what might be most interesting or useful in the field of research, but without structured attempts to align research forces, forward progress in the fields of research and humanity will continue to occur at a sluggish rate.

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Conclusion

Based on exploratory analysis, the major finding of interest was that participants who received percussive therapy after experiencing Exclusion from Cyberball reported significantly reduced pain, irrespective of whether or not vibration was included. Because this particular experiment was designed to isolate the effect of vibration on pain, this finding provides evidence that the vibration used here was not the major factor in the pain reduction effect reported by participants in this experiment. Therefore, other factors included in the experience of percussive therapy, such as physical contact, social and cognitive processes, vibratory settings, and temporal effects warrant future systematic exploration.

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APPENDICES

Appendix I: Institutional Review Board (IRB) Materials

IRB Proposal with Amendments

SECTION 1
1. **Today's date:** 10/10/21
2. **Name:** Alex Luscher
3. **Email:** al9822@bard.edu
4. **Your Academic Program/Department/Office:** Psychology
5. **Your status (faculty, staff, graduate or undergraduate student):**
   Senior Project undergraduate student
6. **Adviser or Faculty Sponsor (if applicable):** Prof. Justin Hulbert
7. **If you are a graduate or undergraduate student, has your Adviser or Faculty
   Sponsor seen and approved your application Adviser approval:** Yes
8. **Your Adviser's or Faculty Sponsor's email address:** jhulbert@bard.edu
9. **Please list all Individuals (full name and status, i.e. faculty, staff, student) involved
   in this project that will be working with human subjects. Note: Everyone listed must
   have completed Human Subject Research Training within the past three years:**
   Name. Alex Luscher [and funding for one research assistant whose name will be
   submitted upon human subject research training certification in an amendment to this
   proposal]
   Status. Senior Project undergraduate student
   [Prof. Justin Hulbert has also completed his Human Subject Research Training, though he
   is not expected to be working with any participants. These two certificates are located in
   Appendix C.]
10. **Do you have external funding for this research:** Yes
11. **If so, state the name of the sponsor and the title of the project as it was submitted to
    that sponsor:**
    Sponsor. Therabody (website: therabody.com; *Therabody*, 2021b)
    Submitted title. Toward a Better Understanding of Percussive Therapy and Pain

SECTION 2
1. **What is the title of your project?** Expanding an Understanding of Social Pain Through
   the Use of a Physical Pain Intervention
2. **When do you plan to begin this project:** Upon approval
3. **Describe your research question(s):**
   Research Question:
   Might the use of a physical intervention to ameliorate the social pain induced by social
   exclusion from a virtual game help clarify the overlapping neural mechanisms between
   social pain and physical pain?
   Important context:
   Social pain and physical pain. Rooted in our current understanding, pain is often divided
   into two major categories: physical pain and social pain. Physical pain involves two
   separate components—sensory (location, quality, intensity) and affective (bothersome,

distressing)—that culminate in an unpleasant experience associated with actual or potential tissue damage. The definition of social pain is similar to that of physical pain in that both are an unpleasant experience that is associated with actual or potential damage. In social pain, however, the threatening force is derived from perceived threats to social connections or social values (Eisenberger, 2012).

The emergence of shared language to describe physical pain and social pain (e.g., *that glass shard hurt my foot* and *that insult hurt my feelings*) provided the first hint to theorizers and researchers that these two pain systems may be related. Numerous studies offer support for the argument that physical pain and social pain involve overlapping neural structures, namely feelings within the affective domain as regulated by the anterior cingulate cortex (Eisenberger, 2012).

Cyberball. This procedure was developed for experimental use and offers two conditions: Social Inclusion and Social Exclusion (pictured to the right; Eisenberger, 2012). A meta-analysis of 120 Cyberball studies provides strong evidence that Cyberball increases measures of social pain (also referred to as ostracism; Hartgerink et al., 2015). Cyberball is a virtual ball-tossing game in which each human participant plays one of three characters on screen. Each participant is randomly assigned to either the Inclusion or Exclusion Condition where the two other on-screen characters are manipulated by the computer program. Participants in the Inclusion Condition will receive the ball an equal number of times throughout the five minutes of gameplay. Participants in the Exclusion Condition will be passed the ball three times, then will never be passed to again. This social exclusion protocol experimentally generates feelings of social pain that allow researchers access to pain theory insights that might otherwise be difficult to measure. Cyberball not only provides a safe, controlled, effective way of experimentally inducing social pain, but it is also simple for researchers to set up and simple for participants to understand (Hartgerink et al., 2015). Because of these factors, Cyberball has become the most widely used protocol for studying the characteristics of social pain since its development (Williams et al., 2000).
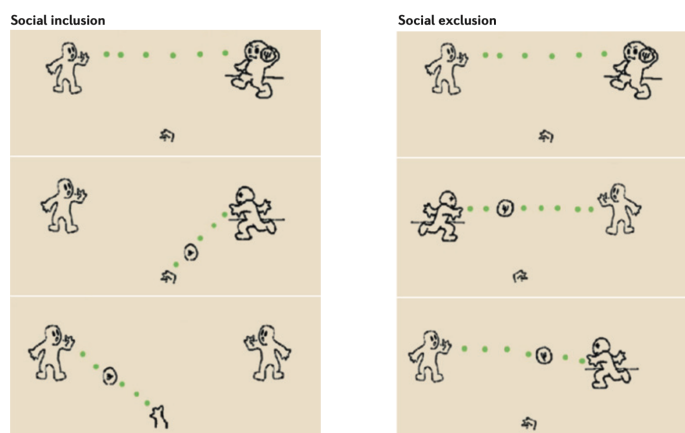
Other experimental pain induction methods, such as those primarily used to study physical pain in humans are limited to brief exogenous stimulation of the skin (Reddy et al., 2012). Experimentally inducing physical pain of higher intensity and duration is unethical in human participants and is therefore reserved for study in animal models (Kaliyaperumal et al., 2020). Because of the evidence for shared mechanisms between physical pain and social pain, Cyberball offers a far more ethical method of pain

induction that can be carefully controlled within an experimental setting. Testing a novel physical intervention for social pain provides an accessible avenue for insight into the underlying neural mechanisms that may or may not be involved in pain regulation while remaining within the scope of a Senior Project.

Physical interventions for social pain. One method to help understand how pain works—a difficult topic over which to gain traction, especially pain that is not caused by acute impact but is psychological in nature and hidden from plain sight—is to explore how the pain can and cannot be ameliorated. Just as physical pain can be lessened by both physical and psychological interventions, there are signs that psychological pain can be reduced similarly. For example, Deckman et al. (2014) offered evidence that marijuana reduces physical pain and social pain. This is an important finding because it suggests that neurochemical systems stimulated by marijuana are involved in both the modulation of physical pain and social pain. Similarly, Rivera et al. (2012) found that stimulation to the right ventrolateral prefrontal cortex (VLPFC) reduces pain caused by Cyberball. This adds evidence that the right VLPFC is also involved in the modulation of social pain. Miller et al. (2014) found that glucose did not reduce social pain induced by Cyberball. Because this experiment did not yield changes in social pain, it is unlikely that the pathways stimulated by glucose are involved in its regulation. Statistically significant or not, this model of pain treatment exploration allows researchers to narrow the fields of the brain that show promise for further investigation.

This Senior Project is informed by all the aforementioned studies and will most closely follow the protocol used by DeWall et al. (2010). Their previous work using a commonly employed, low-risk psychological intervention to model social exclusion has revealed that a pharmaceutical pain reliever (acetaminophen/Tylenol) typically employed to reduce the experience of physical pain can also reduce multiple forms of social pain, including the social pain induced by Cyberball. An fMRI study found that exclusion during Cyberball increased reports of social pain and activity of the dorsal anterior cingulate cortex (dACC) and that administration of acetaminophen reduced reports of social pain and activity in the dACC. This added support for the claim that social pain and physical pain have overlapping neural mechanisms (DeWall et al., 2010). My Senior Project seeks to expand on this work by examining whether a tactile stimulus often applied to physical pain may also decrease social pain through a similar neural pathway. The use of a popular consumer device—Theragun—offers a high degree of experimental control in the application of this tactile stimulus.

Theragun. The Theragun by Therabody harnesses a combination of controlled vibration and pressure to allow individual consumers, coaches, health providers, and researchers to provide safe and effective mechanical massages to themselves or others (Konrad et al., 2020; Roberts, 2020). There is strong evidence that the Theragun decreases delayed onset muscle soreness (physical pain induced through certain forms of exercise, especially eccentric muscle contractions under maximum weight) and decreases muscle tension (as measured by an increase in range of motion; Martin, 2021). In a research partnership with Biostrap, Therabody found initial support for the use of a Theragun to improve various measures of sleep and recovery quality. Of distinct relevance to my Senior Project within

this study, subjective pain ratings decreased by an average of 9% after the use of a Theragun (Biostrap, 2020; Therabody, 2020).

Theraguns can be applied with varying levels of force. Application with more force primes muscles for intense activation. Application with less force, commonly referred to as 'floating,' is intended to promote a relaxation response. Supported in the field, this floating technique was used before bed by participants in the sleep study designed by Therabody and Biostrap to effectively promote relaxation, as quantified by improvements in various sleep metrics (Biostrap, 2020; Therabody, 2020). The same floating technique will be employed in my Senior Project.

I hypothesize that vibration from the Theragun will reduce the feelings of social pain experimentally induced by Cyberball through a relaxation response. Pre-existing conditions that may result in heightened feelings of social pain or physical pain are not of interest to this experiment. The first measurement after participants arrive at the lab are expected to allow the experimenter to control for any variation in pain levels between participants upon arrival to their experimental session. It is ultimately changes in pain levels that are of primary interest.

4. **Describe the population(s) you plan to recruit and how you plan to recruit participants. Please submit all recruitment material, emails and scripts to IRB@bard.edu:**
Target population. The target population is college-age individuals without conditions that present contraindications to any form of tactile stimulation—including the use of a Theragun—where the risks of such treatment may outweigh the benefits. Appendix A includes the exclusion form questions and explanations.

Though some have theorized that certain psychological diagnoses, such as those with high levels of social anxiety, may be more susceptible to adverse reactions after experiencing the Cyberball Exclusion Condition, previous research has found that individual differences—including social anxiety, loneliness, optimism, perceived social support, and self-esteem—did not predict the consequences of social exclusion in the short or long term (Knoll, 2015). Therefore, exclusion based on psychological screening is not necessary for this experiment.

Recruitment. Flyers will be posted in physical locations and online platforms (e.g., bulletin boards in Olin Hall and Bard Students Facebook Group) and handed out to potential participants (e.g., tabeling outside the Bertelsmann Campus Center and Kline). The flyer will contain either a QR code or hyperlink to Qualtrics where potential participants will read a brief description of the nature of the experiment and be invited to complete a pre-screening questionnaire that will occupy a few minutes and determine their eligibility. This questionnaire is located in Appendix A. If participants are eligible to participate, they will be invited to schedule a 30-minute testing slot. An example of the recruitment flyer is located in Appendix F.

5. **Will your participants include individuals from vulnerable or protected populations (e.g., children, pregnant women, prisoners, or the cognitively impaired)?** No

6. **If your participants will include individuals from the above populations, please specify the population(s) and describe any special precautions you will use to recruit and consent:** Not applicable
7. **Approximately how many individuals do you expect to participate in your study?**
   Based on an a priori power calculation performed in G*Power, the total target sample size is 54 (Faul et al., 2009).

Phase	Participants Per Condition	Participants Per Phase	Estimated Effect Size
Pilot	7	14	$f = .7$
Experimental	8	16	$f = .65$
Replication	6	24	$f = .65$
	Total Participants	54	

Because this experimental procedure is novel in many ways, the aforementioned studies of closest design were relied upon to provide the assumptions listed in the table above that were necessary to perform an *a priori* analysis in the statistical program G*Power (Faul et al., 2009). In a meta-analysis of over 120 Cyberball studies, the ostracism effect—of which social pain is a major part—translated to an average Cohen's f of .7 (Hartgerink et al., 2015). This effect size was adopted for the Pilot Phase analysis. Similarly, acetaminophen's effect on social pain, as quantified by the relative activation of areas within the dorsal anterior cingulate cortex (dACC), translates to a range of Cohen's f from .27 to .92 (DeWall et al., 2010). An effect size of $f = .65$, located within the range displayed by DeWall et al. (2010), was adopted for the Experimental Phase and Replication Phase analyses. For each of the three phases, a conventionally used power of .8 was chosen (Pataky et al., 2018). As outlined in the above table, the calculations within G*Power resulted in an output that called for 14 participants (seven per condition) in the Pilot Phase, 16 participants (eight per condition) in the Experimental Phase, and 24 participants (six per condition) in the Replication Phase.

8. **Describe the procedures you will be using to conduct your research. Include descriptions of what tasks your participants will be asked to do, and about how much time will be expected of each individual. NOTE: If you have supporting materials (printed surveys, questionnaires, interview questions, etc.), email these documents separately as attachments to IRB@bard.edu. Name your attachments with your last name and a brief description (e.g., "WatsonSurvey.doc").**
   Exclusion Form. During participant recruitment, interested participants will be invited to scan a QR code or click a hyperlink located on a flyer. This will bring potential participants to Qualtrics, where they will read a brief description of the nature of the experiment and be invited to complete a pre-screening questionnaire that will occupy a few minutes and determine their eligibility. The exclusion form questions and explanations are located in Appendix A. An example recruitment flyer is located in Appendix F. If participants are eligible to participate, they will be invited to schedule a

30-minute time slot.

Scheduling. Participants will be asked to schedule through Calendly (website: calendly.com; *Calendly*, 2021). Individuals will be prompted to sign up for a time slot with their email address, which will only be used for scheduling purposes and deleted after the appointment has occurred.

Pre-arrival email. In the appointment confirmation email, participants will be asked to wear clothing that will be comfortable when worn seated or lying down and to avoid wearing extra loose clothing that may obstruct tactile stimulation.

Location. The Calendly booking confirmation and the pre-arrival emails will both indicate that the experiment session is at a physical location. My Senior Project Adviser, Prof. Justin Hulbert, has a few testing rooms in Preston Hall for his Memory Dynamics Lab. Since the space belongs to the Memory Dynamics Lab, their researchers and participants will be given first priority. It seems likely that their lounge, which has ample space and a desktop, will be available for my use. Should conditions require it, the procedures for this experiment can all be performed in an alternate location including an outdoor setting, weather permitting.

In-lab timeline.
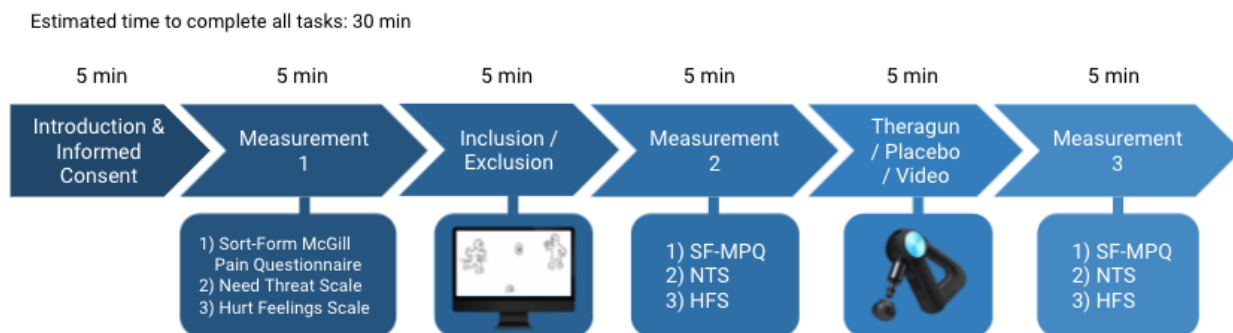
When participants arrive at the lab, they will be greeted by the experimenter and asked to be seated in front of a computer. First, participants will be asked to read the informed consent form located in Appendix B. For participants who consent, they will be asked to complete four validated measures of social pain: Short-Form McGill Pain Questionnaire, Wong-Baker FACES Pain Rating Scale Need Threat Scale, and Hurt Feelings Scale. After participants complete the questionnaires, they will be asked to play Cyberball. Then they will be asked to complete the questionnaires a second time. In the Pilot Phase, participants will be asked to watch a video. In the Experimental and Replication Phases, participants will be offered a vibration massage to their calves, hamstrings, glutes, and back. Next, participants will be asked to complete the questionnaires a third time. Finally, participants will be thoroughly debriefed before leaving the lab.

Phases. Three study phases (Pilot, Experimental, Replication) with six total conditions.

Phase	Cyberball	Intervention

Pilot Condition 1	Inclusion	Video
Pilot Condition 2	Exclusion	Video
Experimental Condition 1 / Replication Condition 2	Exclusion	Theragun
Experimental Condition 1 / Replication Condition 2	Exclusion	Placebo
Replication Condition 3	Inclusion	Theragun
Replication Condition 4	Inclusion	Placebo

The goal of the Pilot Phase is to validate that the Cyberball Exclusion task induces higher feelings of social exclusion and social pain than the Cyberball Inclusion task, that the chosen self-report measures are robust enough to detect changes in these feelings, and that the measures are not compromised by repeated use within a single 30-minute session. The goal of the Experimental Phase is to detect whether feelings of social pain decrease after treatment with a Theragun as compared to an active placebo. The goal of the Replication Phase is to strengthen the findings from the Experimental Phase through replication and to explore the effect of either Theragun treatment or the active placebo on participants who are not experiencing increased levels of social pain.

Measurements. Each of the three measurement periods will each include four validated measures of social pain: Short-Form McGill Pain Questionnaire (Melzack, 1987; Wright et al., 2001), Wong-Baker FACES Pain Rating Scale (Aziato et al., 2015; Wong & Baker, 2013), Need Threat Scale (Gerber et al., 2017; Williams, 2009), and Hurt Feelings Scale (DeWall et al., 2010; Leary & Springer, 2001). The exact wording of the questions can be found in Appendix D along with explanations regarding the measurement purpose of each question. Each of the three measurement periods is expected to take approximately five minutes.

Cyberball. The in-lab computer will have the latest version of Cyberball (5.0) installed and prepared for launch by the time each participant arrives at the lab (Williams, 2012). When participants reach the Cyberball segment of the experiment, they will be provided with the straightforward gameplay instructions: "When you receive the ball, use the mouse to click on the player that you would like to pass to." To better understand what Cyberball gameplay looks like, here is a link to a screen recording of Cyberball gameplay from the participant perspective (note that this particular experimenter designed a Cyber-Fruits start screen that will not be included in this experiment; johann10000, 2009).

The majority of Cyberball studies maintain a cover story based on the one employed in the original Cyberball study published over two decades ago. That is, participants were told that the purpose of the experiment was to study "the utility of the computer as a tool in mental visualization" (Williams et al, 2000). The current experimental procedure will

utilize these same directions, which can be found in Appendix G. This section will take approximately three minutes.

Theragun. During Theragun application for participants in the Theragun condition, the Theragun will be applied at 2400 Hz in the 'floating' or lightest force range. The OLED display on the Theragun will provide the experimenter with visual confirmation that both of these criteria are being met. Additionally, the Theragun will be connected via Bluetooth to the Therabody application installed on the experimenter's smartphone. This app also provides a secondary confirmation of frequency, an alternative pressure gauge, and a timer that will be utilized for each region. In each of the ten regions, the experimenter will spend 30 seconds sweeping the designated area. A sweep is defined as a continuous motion that spans the entire length of the muscle belly without ever stopping in place. In order, the Theragun will be applied to the following regions: 1) right calf (medial and lateral gastrocnemius); 2) left calf; 3) right hamstrings (biceps femoris and semitendinosus); 4) left hamstrings; 5) right glute (gluteus maximus); 6) left glute; 7) right lower back (latissimus dorsi); 8) left lower back; 9) right upper back (trapezius); 10) left upper back. This section will take approximately five minutes.

Treatment Table. Alexis Peters, a former Assistant Athletic Trainer at Bard, indicated that there is at least one extra portable athletic training table that is designed to be comfortable for treatment of athletes anywhere outside the athletic training room. This padded table will offer a comfortable spot for participants in the Theragun and Placebo Conditions to lay face down. After each participant leaves the lab, the table will be wiped down with disinfectant. If the table from the Athletic Trainers at Bard is no longer available, as expected, access to an alternate table of similar comfort and specifications will be acquired.

Video. Participants in the Pilot Phase will view <u>this video</u> for five minutes (9:09 - 14:09; simple happiness, 2021). This video was chosen because it meets the following criteria: 1) 4K footage; 2) no humans; 3) no man-made structures; 4) no animals; 5) subjectively beautiful footage. Since Cyberball relies on social cues, showing footage of nature without any evidence of social creatures—humans and other animals—is of paramount importance. The goal for this video is to occupy five minutes and not to influence feelings of social inclusion or exclusion. Additionally, since participants in the Experimental and Replication Conditions will not experience music at any time, the audio will be turned off.

Compensation. Recruiting in-person participants always presents a challenge to researchers. This challenge is expected to be heightened due to the COVID-19 pandemic guidelines which have ruled our lives over the past 13 months. Offering participants a higher rate of $15.00 per session is expected to increase the number of participants willing to leave their homes in the pursuit of participating in this lab.

9. **Describe any risks and/or benefits your research may have for your participants:**
   Approximately 20 participants will experience social exclusion from the Cyberball Exclusion task. This procedure involves the highest level of risk because it is the only

condition that involves being left out of a virtual ball-tossing game when two virtual players stop passing the ball to the participant after the participant receives the ball three times.

Risks: Psychological discomfort. It is possible that some participants may experience slight discomfort when reflecting on their feelings. While such reflection is considered to be a normal part of everyday life, some may experience mild psychological discomfort. It is also possible that participants may experience feelings similar in nature to playing a physical ball-tossing game with friends that they might consider positive, neutral, or negative.

Physical discomfort. It is also possible that some participants may experience some discomfort during their Theragun session. Participants will be screened to ensure that this Theragun treatment is their first. Therefore, participants may be initially surprised by the feeling. Generally, this feeling of surprise gives way to a feeling of satisfaction. If participants are unaware of a condition that presents a contraindication to the use of a Theragun, they may experience pain or burning. In this case, treatment will be stopped immediately.

Benefits. While this research experiment is not expected to provide participants with any direct benefits, taking part in this study may offer participants the chance to learn about the research process and contribute to our scientific understanding of perceptual changes from a virtual ball-tossing game and a video.

10. **Describe how you plan to mitigate (if possible) any risks the participants may encounter:**
    Informed consent. During the informed consent process, participants will be made aware of the risks involved in the experiment and the resources available to them for support, should an unexpected case of emotional distress present. Resources include the Bard Counseling Center (at 845-758-7433), BRAVE (at 845-758-7777), and the National Alliance on Mental Illness's HelpLine (at 1-800-950-6264). Additionally, it will be made clear that participation is entirely voluntary, and that withdrawal from the experiment is permitted at any time without penalty or judgement.

    Therabody university. Before administering any vibration massage, experimenters will undergo a Theragun training course online via Therabody University. Therabody University is an education platform designed for those administering Theragun sessions to others. Theragun 101 will be required (*Theragun Foundations Course*, 2021). Access to this and all other specialized courses will be provided by Therabody, but their content is outside the scope of application in this experiment.

Theragun sensors
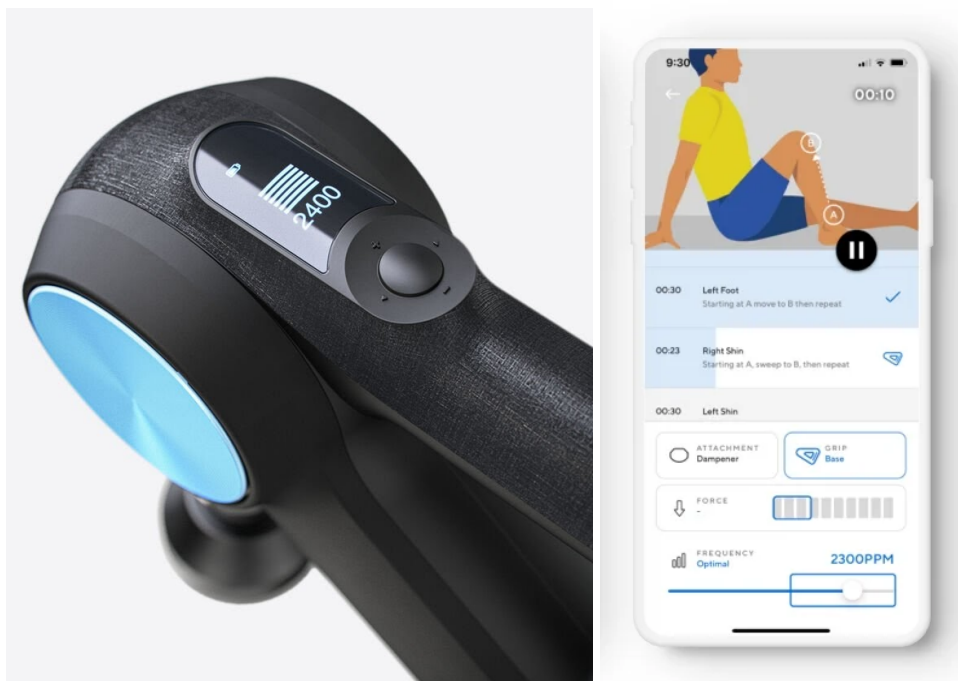
During each vibration massage, experimenters will have multifaceted monitors in place to ensure that the intended vibration frequency and pressure is applied exactly as intended. The built-in OLED display will provide visual confirmation that the Theragun is operating at 2400 Hz and that the 'floating' technique is being applied at the lowest pressure reading (pictured left; *Theragun PRO*, 2021). Additionally, the Theragun will be connected via Bluetooth to the Therabody application installed on the experimenter's smartphone (pictured right; *Therabody App*, 2021). This app will provide a secondary confirmation of frequency, an alternative pressure gauge, and will visually alert the experimenter when it is time to move to the next region, which region to move to next, and how to sweep the area. Importantly, these visual cues will remain outside the participant gaze so that their session is not biased by these feedback mechanisms.

Professional consultants. Justin Hulbert (Assistant Professor of Psychology at Bard College), Alexis (Lexi) Peters (former Assistant Athletic Trainer for Bard College Athletics), Tim Roberts (Director of Science + Innovation at Therabody), and Michael Philips (Senior Science and Research Manager at Therabody) were all involved in the creation of the protocol designed for use in this study. As my Senior Project Adviser, Prof. Justin Hulbert has offered countless pieces of wisdom that strengthened the design of this experiment and constantly challenged me to consider the risks and benefits to every experimental decision. Lexi's knowledge of and experience with Theragun use on athletes within her field has helped contribute to my awareness of participant safety during the design and implementation of each Theragun session. Tim and Michael have been very kind in sharing their experience within the Theragun research field and have provided me with resources to strengthen the theoretical grounding of this work. Each of these individuals is excited to continue to support my work throughout the remainder of the Senior Project process.

Personal experience. I have been using a device similar in action to the Theragun on my body, the bodies of my baseball and squash teammates, and the bodies of my friends on a daily basis for the past three years. This familiarity with the device will serve me well during each Theragun session for this experiment.

Surprise. For participants that display surprise at the beginning of their Theragun session, the experimenter will ask participants if they would like to continue their Theragun session. It is expected that the vast majority of participants will desire to continue their treatment. For those who do not wish to continue their treatment, the experimenter will reserve judgement, end the session immediately, will note the event for participant exclusion reporting purposes, and will remove the participant's data from the aggregated data set.

Pain or Burning. Before the Theragun session, the experimenter will remind participants to immediately make them aware of any significant pain or burning. In the unlikely event that a participant is not aware of a preexisting condition that presents a contraindication to the use of a Theragun, that participant may be more at risk to feel pain or burning. In any case, these side effects are rare, especially given the light, floating technique utilized in this procedure. If any participant experiences significant pain or burning, the Theragun will be stopped immediately and the participant will be referred to Bard Emergency Medical Service (EMS; 845-758-7777) for physical assessment. The Bard EMS team is trained to respond rapidly, evaluate medical conditions, determine if a higher level of care is necessary and arrange for transportation to that location (hospital emergency department or urgent care clinic) if necessary. Of course, the presence of a painful or burning sensation does not mean that the Theragun has caused an injury. It does mean that the participant risk for injury outweighs the research benefit for that particular participant. Regardless, this protocol is in place as a precaution to avoid any situation that places the participant at undue risk and to ensure the experimenter is well prepared for all forms of risk management.

Sanitation. After each participant finishes their session, the Theragun, table, computer station, and any other areas that the participant touched will be wiped down with disinfectant (e.g., Clorox Disinfecting Wipes).

11. **Describe the consent process (i.e., how you will explain the consent form and the consent process to your participants):**
Participants will be given ample time to read and understand the consent form on a computer screen. For participants who choose to move forward with the experiment, their consent will be given in the form of an electronic signature on Qualtrics. See Appendix B for the full consent form.

12. **Have you prepared a consent form and emailed it as an attachment to IRB@bard.edu?** Yes

13. **If you are collecting media capture (video, audio, photos), have you included a section requesting consent for this procedure(s) in your consent form(s)?**
Not applicable

14. **If your project will require you to employ a verbal consent process (no written consent forms), please describe why this process is necessary and how verbal consent will be obtained and stored:** Not applicable

15. **What procedures will you use to ensure that the information your participants provide will remain confidential and safeguarded against improper access or dissemination?**

Exclusion form. Located in Appendix A, this form is necessary to prevent participants with known contraindications to tactile stimulation from receiving tactile stimulation. Importantly, the form never asks participants for their names and offers generic 'yes' or 'no' choices to groups of conditions. If a participant has one or more of the conditions listed in the first group of conditions, the participant would answer 'yes,' excluding them from the study without revealing which condition the participant specifically has. The type of condition is not a measure of interest for this experiment and would therefore unnecessarily violate participant privacy. Answering 'no' to every question in the form will grant access to participants to schedule a 30-minute session.

Scheduling. Eligible participants will be asked to sign up for a 30-minute session through Calendly. To use this service, participants will be asked for their email, which will allow experimenters to contact participants prior to their session with important information. After the session is complete, the appointment and participant email will be deleted from the server.

Data collection. For the purposes of maintaining confidentiality, participant contact information will be linked to the rest of your data by an arbitrary alphanumeric participant code. The linking document will be stored separately from the rest of the data on a password-protected computer. After completion of data collection through Qualtrics, the data will be downloaded and deleted from the Qualtrics servers.

Data analysis and reporting. No personally identifying data will be shared with outside parties. Unless required by law, only the study investigator, members of their research team, and Bard's Institutional Review Board may be granted access to review records from this experiment. All of these theoretically authorized viewers are required to ensure that your identity remains confidential at all times. All reporting methods—which may include posting raw data on OSF.io, sharing between academic researchers, publications, and presentations—will include only data points, not personally identifying information.

16. **Will it be necessary to use deception with your participants at any time during this research? Withholding details about the specifics of one's hypothesis does not constitute deception, this is called incomplete disclosure. Deception involves purposefully misleading participants about the nature of the research question or about the nature of the task they will be completing:** Yes

17. **If your project study includes deception, please describe here the process you will use, why deception is necessary, and a full description of your debriefing procedures:**

Placebo. Approximately 20 (of 54 total) participants will be randomly assigned to the Placebo Condition where they will be told that the Theragun operates at hypersonic frequencies above and beyond the frequency of conscious hearing and feeling. In reality,

the experimenter will apply a Theragun that remains switched off for the full five minutes. It is important to include this condition as an active control so that the characteristic effect of vibration that creates the Theragun experience becomes isolated from the effect of pressure alone and from the effects of other potential unforeseen confounding variables that occur during the experimental procedure. Many experiments, such as the aforementioned Therabody and Biostrap sleep study, failed to include an active control condition (Biostrap, 2020). This severely limits the findings because there is no evidence that the mechanisms triggered by the Theragun impact sleep above and beyond participants' expectations for it to do so.

It remains unclear whether the Theragun Condition will reduce the feelings of social exclusion. After data collection is complete, participants in the Placebo Condition will be told that the Theragun remained off for their treatment period. Due to the possibility that the Theragun treatment reduces the effects of social exclusion from the Cyberball Exclusion Condition, participants in the Placebo Condition will be offered the actual Theragun treatment procedure if they wish to receive it and will be asked whether they would like to remove their data from the experiment in light of the new information. The complete debriefing statement is located in Appendix E.

Cyberball. All participants will play one of two versions of Cyberball. Before playing, they will be presented with a set of directions that indicates how to play, the purpose of the game, and the mental framework they should utilize while they play. In the Pilot Phase of the experiment, it became clear, due to the data collected, behavioral observations during the experiment, and conversations after the experiment, that during Cyberball gameplay, participants 1) did not understand how to play and 2) felt lost due to a lack of stated purpose. In order to address these concerns, a visualization cover story with explicit directions will be added to the existing directions. This cover story was removed for the Pilot Phase in accordance with the findings from Zadro et al. (2004). Because the Pilot Phase was unable to replicate their results under the specific conditions of the laboratory space used in this experiment, the addition of the cover story has now been deemed necessary for Cyberball to induce its intended effect of social pain by directly addressing the two aforementioned concerns. The use of this cover story is the standard for over 100 studies that have utilized Cyberball as part of their experimental procedure (as described in the original Cyberball study by Williams et al., 2000). The full text for these directions can be found in Appendix G.

In the debriefing statement located within Appendix E, participants will receive an explanation of Cyberball's true purpose, along with details to help identify which condition they experienced. It will be made clear that any passes made or not made to them throughout the game were computer generated and are not a reflection of any personal characteristics. Mental health resources are also listed as a directory for participants, should they be in need of additional support.

18. **For all projects, please include your debriefing statement. (This is information you provide to the participant at the end of your study to explain your research question more fully than you may have been able to do at the beginning of the study.) All studies must include a debriefing statement. Be sure to give participants the**

opportunity to ask any additional questions they may have about the study:
See Appendix E

19. **If you will be conducting interviews in a language other than English, will you conduct all of the interviews yourself, or will you have the assistance of a translator? If you will be using the assistance of a translator, that individual must also certify that he or she is familiar with the human subject protocol and has completed the online training course:** Not applicable

20. **If your recruitment or consent forms will be presented in languages other than English, please translate these documents and email copies to IRB@bard.edu. I have submitted all of my translated materials:** Not applicable

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APPENDICES [of Appendix I]

APPENDIX A: EXCLUSION FORM

APPENDIX B: CONSENT FORM

APPENDIX C: HUMAN SUBJECT RESEARCH TRAINING CERTIFICATES

APPENDIX D: SAMPLE QUESTIONNAIRES

APPENDIX E: DEBRIEFING STATEMENT

APPENDIX F: RECRUITMENT FLYER

APPENDIX G: CYBERBALL DIRECTIONS

APPENDIX A: EXCLUSION FORM

Your answers to this questionnaire will only be used to determine whether you are eligible to participate in this experiment. Once eligibility is determined, this document will be destroyed, with no link between you and your responses retained.

Please check 'yes' or 'no' to the best of your awareness for each group of questions:
1. Do you currently have any of the following on your back or legs?
    a. Rash
    b. Blister
    c. Bruise
    d. Wound
    e. Tumor
    f. Injury
    g. Bone fracture
    h. Myositis ossificans (formation of hard, bone tissue inside muscle after injury)
        ☐ yes   ☐ no
2. Do you have any of the following conditions?
    a. Deep vein thrombosis (blood clot)
    b. Hypertension
    c. Cardiac disease
    d. Liver disease
    e. Kidney disease
    f. Bleeding disorder
    g. Neurological conditions that affect taste or smell
    h. Connective tissue disorder
    i. Peripheral vascular insufficiency or disease
    j. Scoliosis or other spinal deformity
        ☐ yes   ☐ no
3. Do you...:
    a. have any hardware surgically implanted in your back or legs?
    b. take anticoagulant or antiplatelet medication (blood thinners)?
    c. have a history of embolisms (obstructed arteries)?
        ☐ yes   ☐ no
4. Do you have any of the following devices?
    a. Pacemaker
    b. Implantable cardioverter-defibrillator
        ☐ yes   ☐ no
5. Have you heard of, seen, or used a handheld massage device, such as a Theragun?
        ☐ yes   ☐ no
    If yes, can you briefly describe what the device looked like and felt like?

    _____
    _____
    _____

[Note to IRB. To be completed during participant recruitment. Individuals will express their interest in participating in this experiment by scanning the QR code located on the physical flyers or by clicking the hyperlink on the virtual flyers. This will bring them to an online version of this form hosted on Qualtrics. If a participant selects 'no' for every answer, they will be invited to schedule their 30-minute in person experiment time. The exclusion criteria in questions 1-4 was based on physical contraindications to manual therapy reported by (Cheatham & Stull, 2018; Therabody, 2021a). Question 5 is important to filter out those with previous understanding and experience that would prevent the efficacy of the Placebo Condition and may alter their reaction to the treatment. Previous research has found that individual differences—including social anxiety, loneliness, optimism, perceived social support, and self-esteem—did not predict the consequences of social exclusion (Knoll, 2015). Therefore, exclusion based on psychological screening is not necessary for this experiment.]

APPENDIX B: CONSENT FORM

BARD COLLEGE
A College of the Liberal Arts and Sciences
Division of Science, Mathematics & Computing

INFORMED CONSENT AGREEMENT

Title: Expanding an Understanding of Social Pain Through the Use of a Physical Pain
Intervention
Principal Investigator: Alex Luscher
Senior Project Adviser: Prof. Justin Hulbert
Institution: Bard College

Informed Consent Form
You are invited to participate in a research study investigating changes in perception caused by a
virtual ball-tossing game. In your 30-minute session at Preston Hall, you may be asked to fill out
questionnaires, play a virtual ball-tossing game, watch a video, and/or receive tactile
stimulation.

To make an informed judgment regarding your decision to participate, you should be sufficiently
informed about the risks and benefits of participation. This consent form outlines what you might
expect from participating in the experiment. Further instructional information will be provided
throughout the experiment, along with opportunities to ask questions. Additionally, I will provide
further details about our ongoing research at the end of the experiment, during what is called a
"debriefing."For now, please read the following information and determine whether you are
both eligible and interested in participating. When you are ready, you will be asked if you wish to
participate. To consent, please sign electronically in the space provided at the end of this form.
Please know that you can choose not to participate, and you can choose to end your
participation at any time during the study without consequence.

Overview of your participation. Should you be eligible and decide to participate, you will first
be asked to reflect on your feelings and answer a number of questions accordingly. Roughly 10
minutes after your arrival, you will be asked to play a video game on the computer in which a
ball is passed between yourself and two other players. Then you will be asked to answer a second
round of questions. Roughly 20 minutes after your arrival, some participants will be asked to lie
facedown on a massage table where the experimenter will offer a vibration massage along their
calves, hamstrings, glutes, and back. For other participants, this will not be necessary and a
relaxing video will be played instead. After that, you will be asked to answer a final set of
questions. The total session will take approximately 30 minutes.

Risks. It is possible that some participants may experience slight discomfort when reflecting on
their feelings. While such reflection is considered to be a normal part of everyday life, some may
experience mild psychological discomfort. It is also possible that participants may experience
feelings similar in nature to playing a physical ball-tossing game with friends that they might
consider positive, neutral, or negative.

If you happen to experience emotional distress, you are encouraged to contact one of the following resources: Bard Counseling Center (at 845-758-7433), BRAVE (at 845-758-7777) or the National Alliance on Mental Illness's HelpLine (at 1-800-950-6264). Additionally, it is important to know that participation is entirely voluntary, and you are welcome to withdraw at any time. If you do not complete the experiment, you will have the option to remove your data from consideration in this research.

During vibration massages, some participants report feeling rapid taps and/or warmth. If the taps or heat from the vibration massage treatment become unpleasant at any time, you will have the option to end the treatment session by simply asking your experimenter to please stop. In the unlikely event that you experience significant pain or burning at any time, please tell the experimenter immediately. The Bard Emergency Medical Service (845-758-7777) can be dispatched at any time for physical assessment to determine if a higher level of care is necessary.

Benefits. While this research experiment is not expected to provide participants with any direct benefits, taking part in this study may offer participants the chance to learn about the research process and contribute to our scientific understanding of one's experiences playing a video game before and after a vibration massage or a relaxing video. Additionally, you may find the vibration massage to be pleasant.

Compensation. To thank you for your participation in this 30-minute experiment, you will receive $15.00.

Your participant rights. Your participation in this experiment is completely voluntary and you may withdraw from the experiment at any time without penalty. You will still receive prorated compensation for the amount of time you were enrolled in the study. At any time, you may withdraw by notifying the experimenter that you no longer wish to participate.

After removing any personally identifiable features from the data, all raw data will be posted online in an open-access database (OSF.io) to facilitate the accumulation and sharing of scientific advances. Additionally, the results of this experiment may be presented at scientific or professional meetings or published in scientific journals. To reiterate, your individual privacy will be maintained in all published and written data resulting from the study. At the conclusion of the study, a debriefing session will take place in which the experimenter will tell you more about the study's aims and hypotheses in greater detail. If you have further questions about the experiment or wish to receive a copy of any manuscripts resulting from this research, you may contact the principal investigator—Alex Luscher—at al9822@bard.edu.

Confidentiality. Your contact information will only be collected for the purpose of scheduling appointments. This information will be kept separately from data collected in the laboratory. For the purposes of maintaining confidentiality, your contact information will be linked to the rest of your data by an arbitrary participant number. The linking document will be stored separately from both sets of data on a password-protected computer. After completion of data collection through Qualtrics, the data will be downloaded and deleted from the Qualtrics servers.

No personally identifying data will be shared with outside parties. Unless required by law, only the study investigator, members of their research team, and Bard's Institutional Review Board will have the authority to review your study records. All are required to ensure that your identity remains confidential. All reporting methods—which may include publications, presentations, and between academic researchers—will include only data points, not personally identifying information.

Research Support
This research project is made possible, in part, by funding from the Bard Psychology Program and Therabody, producers of the Theragun.

Questions? If you have any questions about this study, please contact the principal investigator, Alex Luscher, at al9822@bard.edu or his faculty supervisor, Prof. Justin Hulbert, at jhulbert@bard.edu. If you have questions about your participant rights, please contact the Bard College Institutional Review Board at irb@bard.edu.

STATEMENT OF CONSENT:
"The purpose of this study, procedures to be followed, and the risks and benefits have been explained to me. I have been given an opportunity to ask questions, and my questions have been answered to my satisfaction. I have been told whom to contact if I have additional questions. I have read this consent form and agree to be in this study, with the understanding that I may withdraw at any time."

By signing below, I agree with the above **statement of consent** and further certify that I am at least 18 years of age.

_____   _____
Participant signature   Date

_____
Participant name (printed)

[This consent form was strengthened through reference to Hulbert (2016) and Lopez (2020).]

APPENDIX C: HUMAN SUBJECT RESEARCH TRAINING CERTIFICATES

Completion Date 15-Jan-2020
Expiration Date 14-Jan-2024
Record ID 34879460

This is to certify that:

Alex Luscher

Has completed the following CITI Program course:

Bard College at Simon's Rock (Curriculum Group)
Human Subjects Researchers - Faculty/Staff (Course Learner Group)
1 - Basic Course (Stage)

Under requirements set by:

Bard College at Simon's Rock

Verify at www.citiprogram.org/verify/?wf11c3a5e-16bd-4702-a404-1d91bdc2b765-34879460

Completion Date 05-Apr-2019
Expiration Date 04-Apr-2023
Record ID 31214143

This is to certify that:

Justin Hulbert

Has completed the following CITI Program course:

Human Subjects Research (Curriculum Group)
Researchers and Staff (HSR) (Course Learner Group)
1 - Basic Course (Stage)

Under requirements set by:

Bard College

Verify at www.citiprogram.org/verify/?wd5552c2f-4ffc-4092-97ca-8239ceaa3f1f-31214143

APPENDIX D: SAMPLE QUESTIONNAIRES

		NONE	MILD	MODERATE	SEVERE
1.	**THROBBING**	0) _____	1) _____	2) _____	3) _____
2.	**SHOOTING**	0) _____	1) _____	2) _____	3) _____
3.	**STABBING**	0) _____	1) _____	2) _____	3) _____
4.	**SHARP**	0) _____	1) _____	2) _____	3) _____
5.	**CRAMPING**	0) _____	1) _____	2) _____	3) _____
6.	**GNAWING**	0) _____	1) _____	2) _____	3) _____
7.	**HOT-BURNING**	0) _____	1) _____	2) _____	3) _____
8.	**ACHING**	0) _____	1) _____	2) _____	3) _____
9.	**HEAVY**	0) _____	1) _____	2) _____	3) _____
10.	**TENDER**	0) _____	1) _____	2) _____	3) _____
11.	**SPLITTING**	0) _____	1) _____	2) _____	3) _____
12.	**TIRING-EXHAUSTING**	0) _____	1) _____	2) _____	3) _____
13.	**SICKENING**	0) _____	1) _____	2) _____	3) _____
14.	**FEARFUL**	0) _____	1) _____	2) _____	3) _____
15.	**PUNISHING-CRUEL**	0) _____	1) _____	2) _____	3) _____

NO PAIN |———————————————————————— | **WORST POSSIBLE PAIN**

0 NO PAIN	_____
1 MILD	_____
2 DISCOMFORTING	_____
3 DISTRESSING	_____
4 HORRIBLE	_____
5 EXCRUCIATING	_____

Short-Form McGill Pain Questionnaire. Items 1-11 assess sensory components of pain. Items 12-15 assess affective components of pain. These items are followed by a visual analog scale and Likert-style scale for alternative ratings of overall pain (Melzack, 1987).

Each face represents a person who has no pain (hurt), or some, or a lot of pain. Face 0 doesn't hurt at all. Face 2 hurts just a little bit. Face 4 hurts a little bit more. Face 6 hurts even more. Face 8 hurts a whole lot. Face 10 hurts as much as you can imagine, although you don't have to be crying to have the worst pain. Please choose the face that best depicts the pain you are currently experiencing.

0	2	4	6	8	10
No Hurt	Hurts Little Bit	Hurts Little More	Hurts Even More	Hurts Whole Lot	Hurts Worst

Wong-Baker FACES Pain Rating Scale. The Hurt Feelings Scale (HFS) located in Appendix D is heavily reliant on the interpretation of semantics. While there is also a visual analog scale located within the HFS, it relies on two verbal end marks and a scale void of pain landmarks. The addition of a scale with pain landmark faces allows participants another method of pain reporting that is more visual than verbal (Wong & Baker, 2013).

	For each question, please circle the number to the right that best represents the feelings you were experiencing during the game	Not at all				Extremely
1.	I felt "disconnected"	1	2	3	4	5
2.	I felt rejected	1	2	3	4	5
3.	I felt like an outsider	1	2	3	4	5
4.	I felt I belonged to the group	1	2	3	4	5
5.	I felt the other players interacted with me a lot	1	2	3	4	5
6.	I felt good about myself	1	2	3	4	5
7.	My self-esteem was high	1	2	3	4	5
8.	I felt liked	1	2	3	4	5
9.	I felt insecure	1	2	3	4	5
10	I felt satisfied	1	2	3	4	5
11.	I felt invisible	1	2	3	4	5
12.	I felt meaningless	1	2	3	4	5
13.	I felt nonexistent	1	2	3	4	5
14.	I felt important	1	2	3	4	5
15.	I felt useful	1	2	3	4	5
16.	I felt powerful	1	2	3	4	5
17.	I felt I had control over the course of the game	1	2	3	4	5
18	I felt I had the ability to significantly alter	1	2	3	4	5

.	events					
19.	I felt I was unable to influence the action of others	1	2	3	4	5
20.	I felt the other players decided everything	1	2	3	4	5
21.	Good	1	2	3	4	5
22.	Bad	1	2	3	4	5
23.	Friendly	1	2	3	4	5
24.	Unfriendly	1	2	3	4	5
25.	Angry	1	2	3	4	5
26.	Pleasant	1	2	3	4	5
27.	Happy	1	2	3	4	5
28.	Sad	1	2	3	4	5
	For the next three questions, please circle the number to the right (or fill in the blank) that best represents the thoughts you had during the game					
29.	I was ignored	1	2	3	4	5
30.	I was excluded	1	2	3	4	5
31.	Assuming that the ball should be thrown to each person equally (33%), what percentage of the throws did you receive?	____%				

Need Threat Scale. Items 1-5 assess feelings of belonging. Items 6-10 assess feelings of self-esteem. Items 11-15 assess feelings of meaningful existence. Items 16-20 assess feelings of control. Items

21-28 assess mood. Items 29-31 are a Cyberball Condition manipulation check only to be presented at the last of three measurements. This scale was designed for administration during experiments involving Cyberball and therefore acts as a source of comparison to much of the existing literature (Williams, 2009).

Read each of the following statements carefully and indicate how characteristic it is of you according to the following scale:

        1 = Not at all characteristic of me
        2 = Slightly characteristic of me
        3 = Moderately characteristic of me
        4 = Very characteristic of me
        5 = Extremely characteristic of me

_____   My feelings are easily hurt.

_____   I am a sensitive person.

_____   I am "thick-skinned."

_____   I take criticism well.

_____   Being teased hurts my feelings.

_____   I rarely feel hurt by what other people say or do to me.

Hurt Feelings Scale (Leary & Springer, 2001). This scale has been shown to relate specifically to experiences of social exclusion and not to be confounded with other negative emotions. This scale also acts as a major point of comparison to the original acetaminophen experiment (DeWall et al., 2010).

APPENDIX E: DEBRIEFING STATEMENT

Thank you for participating in this experiment. This research is designed to expand our understanding of social pain through the use of a physical pain intervention. Previous work has argued that social pain and physical pain share neural circuitry, namely the dorsal anterior cingulate cortex of the brain. Based on an expansion of previous work, it was hypothesized here that a vibration massage would ameliorate social pain, just as it does social pain.

The ball-tossing game you played was Cyberball—the most widely used method for the experimental induction of social pain. To enhance this effect, we asked you to practice your "mental visualization skills." While it was not made explicit at the time, the goal of the game was to induce feelings of inclusion or exclusion based on the number of times the ball was passed from the other players to you.

If you received two passes in the beginning of your game and none for the rest of the duration, you were randomly assigned to the Exclusion Condition. Social exclusion in Cyberball has been shown to induce social pain, so I apologize for any unwelcome feelings you may have felt. Do know that you were randomly assigned to this condition and that the players' actions were computer generated. Their actions had absolutely nothing to do with any personal characteristic of yours. If you received about a third of the passes throughout, you were assigned to the Inclusion Condition and provided important control data for comparison.

If you were assigned to the true vibration massage, you surely would have felt the vibration. If you were unsure about whether you felt any tapping or warming sensation during your vibration massage, you were randomly assigned to the Placebo Condition and provided important control data for comparison. If you would like to feel the true vibration massage, I would be more than happy to show you what it feels like upon completion of this form. Similarly, if you watched a video instead of receiving a vibration massage, you provided important data for the assessment of Cyberball's efficacy and other validation of the measures themselves. The same offer for the vibration massage applies to you, too.

The experiment required us to withhold the above information from you in order to avoid contaminating the results in a way that might invalidate the hypotheses being investigated. We apologize for withholding this information until now.

Your data is a critical part of this study because each iteration of this experiment, especially the Control Conditions of mild deception, plays a vital role in the analysis of the results. May we still use your data in our study? As a reminder, all of the data collected today will be stored, analyzed, and reported in a manner that keeps any personally identifiable information confidential. If you have any questions or concerns, you may ask your experimenter now or contact the faculty supervisor, Prof. Justin Hulbert, at jhulbert@bard.edu. Additionally, the following resources are available to you: Bard Counseling Center (at 845-758-7433), BRAVE (at 845-758-7777) or the National Alliance on Mental Illness's HelpLine (at 1-800-950-6264).

Again, thank you for your participation. If you know of any friends or acquaintances that are eligible to participate in this study, we kindly request that you not discuss any details of this

study with them until after they have had the opportunity to participate. Prior knowledge of procedure can invalidate results. Your cooperation is greatly appreciated.

[This debriefing statement was strengthened through reference to the debriefing statements located within Hulbert (2016) and Nelson (2009)]

APPENDIX F: RECRUITMENT FLYER
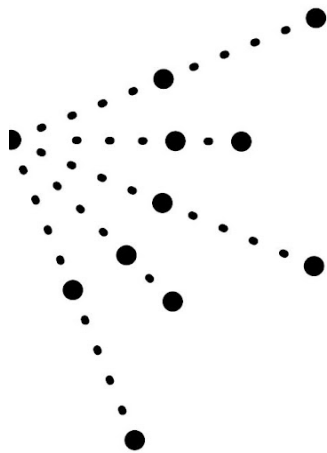
[The current QR code links to Google. When recruitment begins, the QR code will link to Qualtrics, where participants will be able to read about the nature of participation and will be invited to proceed to an eligibility survey. If a participant is eligible, they will either be asked to join a scheduling waitlist or to schedule a 30-minute slot through Calendly, should there be slots available.]

APPENDIX G: CYBERBALL DIRECTIONS

Welcome to Cyberball, the Interactive Ball-Tossing Game Used for Mental Visualization!

In the upcoming experiment, we test the effects of practicing mental visualization on task performance. Thus, we need you to practice your mental visualization skills. We have found that the best way to do this is to have you play an online ball tossing game with other participants who are logged on at the same time.

In a few moments, you will be playing a ball tossing game with other students over our network. The game is very simple. When the ball is tossed to you, simply click on the name of the player you want to throw it to. When the game is over, additional instructions will appear on screen.

What is important is not your ball tossing performance, but that you MENTALLY VISUALIZE the entire experience. Imagine what the others look like. What sort of people are they? Where are you playing? Is it warm and sunny or cold and rainy? Create in your mind a complete mental picture of what might be going on if you were playing this game in real life.

Please check in with your experimenter to ensure that you understand the directions.

Okay, ready to begin? Please click on the continue arrow to begin.

Appendix H: Second Amendments Cover Letter and Approval Letter

Dear members of the Bard IRB,

Attached, you will find the supplemental materials to accompany my application to amend—in a few minor ways—my recently approved proposal, case number 2021JUNE29-LUS ("Toward a Better Understanding of Percussive Therapy and Pain"). For ease of reference, substantive changes are described within this cover letter and highlighted in blue within the documentation itself.

In the time since my previous minor amendment that was approved on 9/8/21, I have run the Pilot Phase of my experiment (as detailed in that minor amendment). Based on the formal data collection and informal conversations with participants after the experiment, it has become clear that the following two phases ought to include some minor adjustments.

In addition to some very minor presentation changes (e.g., bolding important words and adding a few practice questions), there is a more substantial component I would like to amend.

Specifically, I propose the implementation of a standard cover story to the Cyberball directions. In my previous submission, I cited a study that found these directions to not significantly impact participants' feelings of social pain (Zadro et al., 2004). Despite this single study, the standard in over 100 research studies that utilize Cyberball as part of their experimental procedure is to include a cover story that frames the game as a visualization task, when in reality, the experiment is concerned with the number of times a ball is passed to participants (as described in the original experimental procedure within Williams et al., 2000). Because inducing social pain is integral to testing the theory of pain outlined within, it is expected that the addition of this relatively benign deception will help facilitate the purpose of the main experiments. You can find a brief explanation under Question 8 in SECTION 2, the full justification of this addition below Question 17 in SECTION 2, the updated debriefing statement in Appendix E, and the full Cyberball directions text within Appendix G.

These details, plus some grammatical corrections throughout, are not intended to change the scope of my Senior Project or the attendant (minor) risks to participants.

Thank you for your consideration,

Alex Luscher

Bard College

Date: October 12, 2021
To: Alex Luscher
Cc: Justin Hulbert, Deborah Treadway, Brandt Burgess
From: Tom Hutcheon, IRB Chair
Re: Proposed Amendments to 2021JUNE29-LUS

DECISION: APPROVED

Dear Alex,

The Bard Institutional Review Board has reviewed and approved the amendments you submitted to your protocol on October 10, 2021. Your case number remains 2021JUNE29-LUS.

Please notify the IRB if your methodology changes or unexpected events arise.

Tom Hutcheon
IRB Chair
thutcheo@bard.edu

Appendix J: First Amendments Cover Letter and Approval Letter

Dear members of the Bard IRB,

Attached, you will find the supplemental materials to accompany my application to amend—in a few minor ways—my recently approved proposal, case number 2021JUNE29-LUS ("Toward a Better Understanding of Percussive Therapy and Pain"). For ease of reference, notable changes are listed within this cover letter and highlighted in blue within the documentation itself. Specifically:

In Appendix B, you will find the consent form where I have added one sentence that informs participants that their unidentified raw data will be posted online in an open access database and a Research Support section that makes participants aware of the funding sources for this research project (*OSF*, 2021). This addition aims to further align my Senior Project with the major principles of open science and academic freedom by allowing other researchers and interested members of the public to utilize the data collected in this experiment for future work (for more details on this common practice, see Soderberg, 2018);

In Appendix F, you will find an updated example of a flyer design that will be used for participant recruitment;

And, in SECTION 1, you will find a status update about this Senior Project's external funding.

These details, plus some grammatical corrections throughout, are not intended to change the scope of my Senior Project or the attendant (minor) risks to participants.

Thank you for your consideration,

Alex Luscher

Bard College

Date: September 8, 2021
To: Alex Luscher
Cc: Justin Hulbert, Deborah Treadway, Brandt Burgess
From: Tom Hutcheon, IRB Chair
Re: Proposed Amendments to 2021JUNE29-LUS

DECISION: APPROVED

Dear Alex,

The Bard Institutional Review Board has reviewed and approved the amendments you submitted to your protocol on September 8, 2021. Your case number remains 2021JUNE29-LUS.

Please notify the IRB if your methodology changes or unexpected events arise.

Tom Hutcheon
IRB Chair
thutcheo@bard.edu

Appendix K: IRB Proposal Approval Letter

Bard College   Institutional Review Board

Date: June 29, 2021
To: Alex Luscher
Cc: Justin Hulbert, Deborah Treadway, Brandt Burgess
From: Tom Hutcheon, IRB Chair
Re: Toward a Better Understanding of Percussive Therapy and Pain

DECISION: APPROVED

Dear Alex,

The Bard Institutional Review Board has reviewed your revisions and approved your proposal entitled "Toward a Better Understanding of Percussive Therapy and Pain." Your proposal is approved through June 29, 2022 and your case number is 2021JUNE29-LUS.

Please notify the IRB if your methodology changes or unexpected events arise.

We wish you the best of luck with your research!

Tom Hutcheon
IRB Chair
thutcheo@bard.edu

Appendix II: Preregistration

Study Information

Hypotheses

Overall main hypothesis:

2.1) Percussive therapy will reduce the pain associated with social exclusion.

Primary hypotheses:

Pilot:

1.1) Pain scores for participants in Pilot Condition 1 will not differ at Measurements 1, 2, and 3.

1.2) Pain scores for participants in Pilot Condition 2 will differ at Measurements 1, 2, and 3 due to a main effect of time.

Experimental:

2.1) Listed above as main hypothesis.

Replication:

3.1) Pain scores for participants in the Replication Phase will differ at Measurements 2 and 3 due to an interaction between Cyberball, treatment, and time.

Secondary confirmatory hypotheses:

Pilot:

1.2.1) Pain scores for participants in Pilot Condition 2 will increase from Measurements 1 to 2.

1.2.2) Pain scores for participants in Pilot Condition 2 will not differ from Measurements 2 to 3.

1.2.3) Participants in Pilot Condition 2 will report higher levels of exclusion than participants in Pilot Condition 1.

Experimental:

2.1.1) Pain scores for participants in the Experimental Phase will not differ at Measurement 1.

2.1.2) Pain scores for participants in the Experimental Phase will not differ at Measurement 2.

2.1.3) Pain scores for participants in Experimental Condition 1 will have lower pain scores than participants in Experimental Condition 2 at Measurement 3.

2.1.4) Pain scores for participants in the Experimental Phase will increase from Measurements 1 and 2 due to a main effect of time.

Replication:

3.1.1) Pain scores for participants in the Replication Phase will not differ at Measurement 1.

3.1.2) Pain scores for participants in the Replication Phase will differ at Measurement 2 due to a main effect of Cyberball.

3.1.3) Pain scores for participants in the Replication Phase will differ at Measurement 2 due to a main effect of Cyberball.

3.1.4) Pain scores for participants in the Replication Phase will differ due to an interaction of Cyberball and treatment at Measurement 3.

Design Plan

Study type

Experiment - A researcher randomly assigns treatments to study subjects, this includes field or lab experiments. This is also known as an intervention experiment and includes randomized controlled trials.

Blinding

For studies that involve human subjects, they will not know the treatment group to which they have been assigned.
Is there any additional blinding in this study?
No response

Study design

Pilot: mixed factors design with 2 factors (Cyberball, time), 2 levels (between-subjects Inclusion/Exclusion; within-subjects Measurement 2 (M2), Measurement 3 (M3), and 1 covariate (Measurement 1 (M1)). The goal of the Pilot Phase is 1) to replicate previous Cyberball findings within the conditions of this specific experiment (i.e., that Cyberball Inclusion does not increase pain and that Cyberball Exclusion increases pain as quantified by a visual analog scale (VAS)); 2) to establish the test-retest reliability of the VAS used in this procedure; 3) identify and fix any unforeseen areas of human error, should they arise.

Experimental: mixed factors design with 2 factors (treatment, time), 2 levels (between-subjects Theragun/Placebo; within-subjects M2, M3), and 1 covariate (M1). The goal of the Experimental Phase is to analyze whether percussive therapy (Theragun) decreases the pain induced by Cyberball as compared to an active Placebo. For this analysis, pain will be quantified by the VAS supported by the Pilot Phase.

Replication: mixed factors design with 3 factors (Cyberball, treatment, time), 2 levels (between-subjects Inclusion/Exclusion, between-subjects Theragun/Placebo, within-subjects M2/M3), and 1 covariate (M1). The goal of the Replication Phase is to replicate the findings of the Experimental Phase and to measure how participants who are not experiencing experimentally-elevated levels of pain (Cyberball Inclusion) respond to the Theragun and Placebo conditions. Pain will be quantified in the same way as the Experimental Phase.
- Study Phases and Conditions.png

Randomization

This experimental procedure will utilize block randomization within each of the phases, such that each block contains exactly as many participants as there are conditions. For example, Block 1 of Phase 1 will have two participants who will randomly be assigned to either Condition 1 or Condition 2 without overlap. This ensures that there will be an equal number of participants per condition, even if extraneous variables cause the experimental data collection period to end before the target number of participants is reached.

Before data collection, each theoretical participant was assigned a random number using the Excel function rand(). From these randomly generated numbers, participants were randomly assigned to conditions using the the Excel function sort (from smallest to largest first by Block, then by rand). This served to randomly shuffle the order of the conditions, which was entered into the Cond column prior to sorting. The final sorting constraint was that one trial phase must be complete before participants in another condition begin.

The resulting order is included below (ID key: the first number serves to minimize participant awareness of how many participants have gone before them should they happen to see their ID, second two numbers indicate participant order, last two characters indicate condition. These IDs allow for easy reference while maintaining participant confidentiality):

Order	Block	rand	Cond	ID

Begin Pilot Phase:

Order	Block	rand	Cond	ID
1	1	0.351	2	101!@
2	1	0.912	1	102!!
3	2	0.023	2	103!@
4	2	0.113	1	104!!
5	3	0.370	1	105!!
6	3	0.972	2	106!@
7	4	0.613	2	107!@
8	4	0.672	1	108!!
9	5	0.744	1	109!!
10	5	0.955	2	110!@
11	6	0.075	2	111!@
12	6	0.251	1	112!!
13	7	0.442	2	113!@
14	7	0.928	1	114!!

Begin Experimental Phase:

Order	Block	rand	Cond	ID
15	8	0.101	1	115@!
16	8	0.613	2	116@@
17	9	0.427	1	117@!
18	9	0.428	2	118@@
19	10	0.650	2	119@@
20	10	0.775	1	120@!
21	11	0.209	1	121@!
22	11	0.853	2	122@@
23	12	0.231	2	123@@
24	12	0.410	1	124@!
25	13	0.022	1	125@!
26	13	0.704	2	126@@
27	14	0.476	1	127@!
28	14	0.610	2	128@@
29	15	0.430	1	129@!
30	15	0.432	2	130@@

Begin Replication Phase:

Order	Block	rand	Cond	ID
31	16	0.048	2	131#@
32	16	0.144	3	132##
33	16	0.304	1	133#!
34	16	0.435	4	134#$
35	17	0.131	2	135#@
36	17	0.379	1	136#!
37	17	0.947	3	137##
38	17	0.981	4	138#$
39	18	0.312	4	139#$

40	18	0.815	2	140#@
41	18	0.822	3	141##
42	18	0.989	1	142#!
43	19	0.366	2	143#@
44	19	0.371	4	144#$
45	19	0.510	3	145##
46	19	0.638	1	146#!
47	20	0.011	2	147#@
48	20	0.150	1	148#!
49	20	0.381	4	149#$
50	20	0.993	3	150##
51	21	0.030	4	151#$
52	21	0.125	1	152#!
53	21	0.370	2	153#@
54	21	0.902	3	154##

Sampling Plan

Existing Data
Registration prior to creation of data
Explanation of existing data
No response
Data collection procedures
A recruit will be deemed ineligible to participate if:
- responds yes to questions 1-4 (see Exclusion Questionnaire file for full list of exclusion criteria)
- responds yes to question 5 and is determined to have a prior of a percussive therapy device. This description will be manually subjectively scored so that participants who are not actually familiar with these devices, but claim to be for any variety of reasons, are included.

Recruiting:
Flyers (see attached document) will be distributed at popular locations for undergraduate students around the Bard College Campus (e.g., Kline Commons, Olin Hall, Bertlsmann Campus Center) and on popular social media boards (e.g., Bard Students Facebook Group)

Scheduling:
Participants will sign up for a single 30-minute session through Calendly

Timeline:
Each participant will follow the timeline attached below.

Payment:
$15.00 (funded by Therabody and the Bard Psychology Program)
- Participant Timeline.png
- Exclusion Questionnaire.pdf
- Flyer.pdf

Sample size
Pilot: 14 participants (7 per condition)

Experimental: 16 participants (8 per condition)
Replication: 24 participants (6 per condition)

Sample size rationale

Because this experimental procedure is novel in many ways, the aforementioned studies of closest design were relied upon to provide the assumptions listed in the table above that were necessary to perform an a priori analysis in the statistical program G*Power (Faul et al., 2009). In a meta-analysis of over 120 Cyberball studies, the ostracism effect—of which social pain is a major part—translated to an average Cohen's f of .7 (Hartgerink et al., 2015). This effect size was adopted for the Pilot Phase analysis. Similarly, acetaminophen's effect on social pain, as quantified by the relative activation of areas within the dorsal anterior cingulate cortex (dACC), translates to a range of Cohen's f from .27 to .92 (DeWall et al., 2010). An effect size of f = .65, located within the range displayed by DeWall et al. (2010), was adopted for the Experimental Phase and Replication Phase analyses. For each of the three phases, a conventionally used power of .8 was chosen (Pataky et al., 2018). As outlined in the above table, the calculations within G*Power resulted in an output that called for 14 participants (seven per condition) in the Pilot Phase, 16 participants (eight per condition) in the Experimental Phase, and 24 participants (six per condition) in the Replication Phase.

Stopping rule

Data collection timeline:

Data collection start date: 10/6/21 at 12:00pm ET

Senior thesis data analysis start date: 11/15/21

Data analysis will begin for each condition after the final participant of each condition has participated, unless the target number of participants has not been reached by 11/15/21. In this case, data analysis will begin due to external senior thesis deadlines. Data collection may continue after this senior thesis analysis for use in future projects (such as the pursuit of publication).

<center>Variables</center>

Manipulated variables

Cyberball Inclusion: participants will play Cyberball with two additional virtual players for a total of just over 2 minutes (Dovishaw, 2020). Participants will receive roughly a third of the total passes. Inclusion randomization was performed with the same technique used for participant condition randomization. In the case that throws overlapped after randomization, such as 2 throws in a row to Player 1, the computer players (1,2) were replaced with their counterparts and the human player (0) was replaced with the next computer player until overlaps were removed. The resulting order is as follows:

0,2,1,2,1,0,1,0,2,1,0,2,1,0,2,0,1,2,1,2,0,1,2,0,1,0,2,1,2,0,2,1,0,2,1,0,2,1,0.

Cyberball Exclusion: participants will play Cyberball with two additional virtual players for a total of approximately 2 minutes (Dovishaw, 2020). Participants will be passed the ball 2 times at the start and then will not receive the ball again for the remainder of gameplay. The same randomization technique was used for the first two blocks. After that, the two virtual players pass to themselves in alternating order. The resulting order is as follows:

0,2,1,2,1,0,2,1,2,1,2,1,2,1,2,1,2,1,2,1,2,1,2,1,2,1,2,1,2,1,2,1,2,1,2,1.

Video: participants will be invited to watch a 5-minute video clip https://youtu.be/rTG-vh2SiGQ. This clip was chosen as a control for the Theragun and Placebo treatments because it meets the

following criteria: 1) no humans; 2) no man-made structures; 3) no animals; 4) subjectively beautiful footage. An instruction slide was added to the end of the video to make participants aware of how to proceed.

Testing room: All questions, both Cyberball conditions, and the video will be presented through Qualtrics on an iMac (27-inch, Late 2013). The room temperature will be set to 69 degrees Fahrenheit. The experimenter will wear a light blue lab coat from Red Kap. Due to continued coronavirus concerns, the experimenter and all participants will wear masks.

Theragun: participants will be invited to lay facedown on a massage table (Oakworks Catalog #36639 with an ineckfit face pillow attachment) where a Theragun will be applied by an experimenter at 2400 Hz in the 'floating' or lightest force range. The OLED display on the Theragun will provide the experimenter with visual confirmation that both of these criteria are being met. Additionally, the Theragun will be connected via Bluetooth to the Therabody application installed on the experimenter's smartphone. This app also provides a secondary confirmation of frequency, an alternative pressure gauge, and a timer that will be utilized for each region. In each of the ten regions, the experimenter will spend 30 seconds sweeping the designated area. A sweep is defined as a continuous motion that spans the entire length of the muscle belly without ever stopping in place. In order, the Theragun will be applied to the following regions: 1) right calf (medial and lateral gastrocnemius); 2) left calf; 3) right hamstrings (biceps femoris and semitendinosus); 4) left hamstrings; 5) right glute (gluteus maximus); 6) left glute; 7) right lower back (latissimus dorsi); 8) left lower back; 9) right upper back (trapezius); 10) left upper back. This section will take approximately 5 minutes.

Placebo: the only change from the above Theragun procedure is that the Theragun will be applied at 0 Hz.

Measured variables

All variables will be presented to participants in a testing room on Qualtrics with the exception of the 5-minute Theragun and Placebo treatments. One of six Qualtrics variations will be preloaded on the computer before participants arrive in accordance with the prerandomization. An account similar to what participants may see can be found in the attachment below. Unfortunately, some of the formattings are lost in the .pdf form.

Independent variables:
Cyberball: Inclusion, Exclusion
Treatment: Theragun, Placebo, Video

Dependent variables:
Total pain:
Wong-Baker FACES Pain Rating Scale (FACES). Directions and FACES are presented as written in Wong and Baker (2013) with the addition of a non-anchored slider scale that allows participants to more precisely estimate their pain (Maineri, 2021). Because the lack of an initial anchor makes the utilization of the slider less obvious, an instruction was added to direct participants' attention to its location on the page. This will be the measure of interest for all primary and secondary analyses.

Short-Form McGill Pain Questionnaire (SF-MPQ): items 15 and 16. Item 15 is presented as a visual analog scale. Item 16 is presented as present pain intensity. All three items are presented as written in Melzack (1987).

Social pain:
Needs Threat Scale (NTS): items 1-29. At M2 and M3, NTS is presented exactly as written in Williams (2009). At M1, wording references to Cyberball gameplay were removed due to lack of relevance. Instead of reflecting on gameplay, which would have occurred in the 3 minutes prior to the presentation of the questionnaire, participants were simply asked to reflect on their experience during the past 3 minutes.
Hurt Feelings Scale (HFS). Wording is presented as written in Leary and Springer (2001). Fill in the blanks for each item have been replaced by a Likert-type scale for the purposes of format consistency across questionnaires and scoring.
SF-MPQ items 12-15.
From this list of questionnaires that contain indicators of social pain, the Pilot Condition will be used to choose a single questionnaire for all subsequent primary and secondary analyses in the Experimental and Replication Phases.

Physical pain:
Wong-Baker FACES Pain Rating Scale (FACES). Presented as written in Wong and Baker (2013).
SF-MPQ items 1-11.
This list of questionnaires that contain indicators of physical pain will only be used for the purposes of exploratory analyses.

Time: Measurement 2 (M2), Measurement 3 (M3)

Covariate: The chosen social pain questionnaire score at Measurement 1 (M1)

Manipulation check:
NTS items 30-33
   ● Qualtrics_All.pdf
Indices
Total pain scoring procedures:

Wong-Baker FACES Pain Rating Scale (FACES):
Raw score from single item
This will be used as the main measure for all primary and secondary analyses unless otherwise noted.

Short-Form McGill Pain Questionnaire (SF-MPQ) (following the procedure of Melzack 1987)):
Raw score for item 15
Raw score for item 16

Social pain scoring procedures:

Need Threat Scale (following the procedure of Jamieson, Harkins, and Williams (2010)):
Average belonging subscale items 1-5 (reverse score items 1,2, 3)
Average self-esteem subscale items 6-10 (reverse score item 9)
Average meaningful existence subscale items 11-15 (reverse score items 11, 12, 13)
Average control subscale items 16-20 (reverse score items 19, 20)
Average 4 subscales for the rating of social pain that will be used for this analysis. A lower score indicates higher social pain.

SF-MPQ:
Add items 11-14

Hurt Feelings Scale (following the procedure of Leary and Springer (2001)):
Add items 1-6 (reverse score items 3, 4, 6)

Physical pain scoring procedures:

SF-MPQ:
Add items 1-10

Affective scoring procedure:

NTS:
Average affective subscale items 21-28 (reverse score items 22, 24, 25, 28)

Analysis Plan

Statistical models
Main comparison: to be performed with scores from FACES
2.1) 2 x 2 mixed-factor ANCOVA for participants in the Experimental Phase. 2 factors: treatment, time; 2 levels: between-participants Theragun/Placebo, within-participants M2/M3; covariate: M1; hypothesis: interaction between treatment and time, main effects are qualified by this interaction such that pain decreases over time in the Theragun condition but not the placebo condition. In the case of a significant interaction, secondary post-hoc comparisons will be performed for each one of these factors.

Primary planned comparisons: to be performed with scores from FACES, unless otherwise noted
Pilot:
1.1) one-way repeated measures ANOVA for participants in Pilot Condition 1. 1 factor: time; 3 levels: M1/M2/M3; hypothesis: no reliable main effect or interaction.
1.2) one-way repeated measures ANOVA for participants in Pilot Condition 2. 1 factor: time; 3 levels: M1/M2/M3; hypothesis: main effect of time.
Experimental:
2.1) Listed above as main comparison.
Replication:
3.1) 2 x 2 x 2 mixed factor ANCOVA for participants in the Replication Phase. 3 factors: Cyberball, treatment, time; 2 levels: between-participants Theragun/Placebo, between-participants Inclusion/Exclusion, within-participants M2/M3; covariate: M1; hypothesis: interaction between Cyberball, treatment, and time, main effects are qualified by this

interaction such that pain decreases over time in the Theragun/Exclusion condition but not in the other three conditions. In the case of a significant interaction, secondary post-hoc comparisons will be performed for each one of these factors.

Secondary confirmatory comparisons: to be performed with scores from FACES, unless otherwise noted
Pilot:
1.2.1) repeated-measures t-test: comparison of M1 and M2 for participants in Pilot Condition 2. Hypothesis: statistically different such that M1 is lower than M2.
1.2.2) repeated-measures t-test: comparison of M2 and M3 for participants in Pilot Condition 2. Hypothesis: not statistically different.
1.2.3) between-participants t-test for participants in the Pilot Phase: comparison of Condition 1 and Condition 2 at M2: Hypothesis: statistically different such that participants in Condition 2 have higher pain scores than participants in Condition 1. This is a manipulation check that will be performed twice with NTS items 29+30 and item 31.
Experimental:
2.1.1) between-participants t-test for participants in the Experimental Phase: comparison of Condition 1 and Condition 2 at M1. Hypothesis: not statistically different.
2.1.2) between-participants t-test for participants in the Experimental Phase: comparison of Condition 1 and Condition 2 at M2. Hypothesis: not statistically different.
2.1.3) between-participants t-test for participants in the Experimental Phase: comparison of Condition 1 and Condition 2 at M3. Hypothesis: statistically different such that participants in Condition 1 have lower pain scores than participants in Condition 2.
2.1.4) 2 x 2 mixed factor ANOVA for participants in the Experimental Phase. 2 factors: treatment, time; 2 levels: between-participants Theragun/Placebo, within-participants M1/M2; hypothesis: main effect of time with no reliable interaction.
Replication:
3.1.1) 2 x 2 ANOVA for participants in the Replication Phase at M1. 2 factors: Cyberball, treatment; 2 levels: Inclusion/Exclusion, Theragun/Placebo; hypothesis: no reliable main effect or interaction.
3.1.2) 2 x 2 ANOVA for participants in the Replication Phase at M2. 2 factors: Cyberball, treatment; 2 levels: Inclusion/Exclusion, Theragun/Placebo; hypothesis: main effect of Cyberball with no reliable interaction.
3.1.3) 2 x 2 ANOVA for participants in the Replication Phase at M2. 2 factors: Cyberball, treatment; 2 levels: Inclusion/Exclusion, Theragun/Placebo; hypothesis: main effect of Cyberball with no reliable interaction. This is a manipulation check that will be performed twice with NTS items 29+30 and item 31.
3.1.4) 2 x 2 ANOVA for participants in the Replication Phase at M3. 2 factors: Cyberball, treatment; 2 levels: Inclusion/Exclusion, Theragun/Placebo; hypothesis: interaction of Cyberball and treatment, main effects are qualified by this interaction such that pain is lower in the Theragun Exclusion condition than the Placebo Exclusion condition.
Transformations
All questionnaire coding will be done in accordance with their original design.
Inference criteria
alpha = .05
Data exclusion

If a participant is determined to be eligible for the experiment, their data will be excluded from final analyses if they:
- withdraw their willingness to participate prior to finishing their data collection session. Each question presented to participants requires an answer to continue, so they must answer all the questions in order to finish their data collection session.
- report pain ratings larger than 3 standard deviations from the mean scores within any measurement period (M1, M2, M3) within their condition

Missing data

Participants who wish to leave the experiment prior to the completion of their session will have their data removed. In an attempt to maintain a balanced number of participants in each condition, the very next participant that enters the lab will take the excluded participant's spot.

Exploratory analysis

1) Composite social pain scores—NTS, HFS, and MPQ items 12-15—will be more sensitive to change in repeated measures of social pain over a short period of time. Sensitivity, in this case, refers to the ability to detect a change in social pain perception if such change exists. All the above comparisons can be performed with this composite score in place of the individual social pain questionnaire score. Due to a lack of precedent in the background literature, this hypothesis is exploratory.

2) Physical pain changes concurrently with social pain. Due to the lack of a satisfactory in-lab pain induction method, physical pain will not be induced. Therefore, this change may only be significant in participants who enter the lab with higher baseline levels of physical pain or those who experience increases in physical pain perception due to Cyberball Exclusion.

3) Physical pain as an additional M1 covariate may act as a more sensitive control for individual differences when participants arrive at the lab.

4) Are the NTS, HFS, and SF-MPQ conducive to use within a 30-minute repeated-measures design?

5) Which subscales of NTS, HFS, and SF-MPQ correlate most significantly? This may help clarify the underlying mental processes behind each subscale.

<div align="center">Other</div>

Other

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Appendix III: Open Science Framework

LINKS

Project home: https://osf.io/m9f4e/

Preregistration: https://osf.io/bqetv

Preregistration files: https://osf.io/5djkx/

Qualtrics survey files: https://osf.io/zbwh8/

Raw data: https://osf.io/jwuzd/