Temporal Aspects of the Thermal Grill Illusion of Pain

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Abstract

The thermal grill illusion (TGI) is produced when warm and cool temperatures are simultaneously presented resulting in a hot, burning, painful sensation. The TGI suggests a connection between thermal and pain pathways that, once understood, could lead to a better understanding of pain in general and possible ways to modulate it. The aim of this study was to determine if there is a temporal aspect of the illusion that would affect the way it is felt. Twenty-four subjects participated in this study which revealed that there is no temporal aspect of the thermal grill illusion that affects pain or thermal components of the illusion. These results suggest that studies differing in the temporal component of the illusion may be compared as methodologically equal. Furthermore, temporal differences cannot be the reason for significant differences in experimental results. Future studies should include use of the thermal grill as it shows great promise to a better understanding of the interaction between pain and thermal pathways.

Keywords: thermal grill illusion, temporal effects, thermal and pain processing
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Pain is generally an indication to the body that there is illness or injury present; yet in some situations, pain itself can be a threat to the body. Acute pain that occurs due to a broken limb or sprained wrist or even an insect bite is an example of a type of pain that is helpful to the body as it warns one of harm. Chronic pain, however, is an example of a type of pain that is harmful. Chronic pain lasts beyond the usual course of acute illness and is characterized by persisting for longer than three to six months and adversely affecting an individual’s well-being ("Chronic Pain", 2014). Chronic pain greatly impairs day-to-day life and currently affects 100 million Americans; more than diabetes, heart disease, stroke, and cancer combined (Institute of Medicine Report, 2011). Aside from the obvious decrease in life satisfaction for these individuals, this vast number of people suffering from chronic pain also presents great challenges for society. Chronic pain results in health care costs and productivity losses estimated at $560 - $635 billion annually (Institute of Medicine Report, 2011).

A common side effect for many experiencing chronic pain is disturbed thermal sensitivity (Woolf & Doubell, 1994). These changes can involve disorders such as cold allodynia and hyperalgesia, which are characterized by pain in response to normally non-painful stimuli and oversensitivity to already painful stimuli, respectively. These symptoms can appear across a wide range of chronic pain conditions, from neuropathic pain to fibromyalgia. They suggest that thermal and pain pathways are related and may be even able to modulate each other in some way. Accordingly, understanding the relationship between thermal sensations and pain may lead to greater insight into both chronic and acute pain. The purpose of the current study is to explore this relationship by testing the temporal aspects of what is known as the thermal grill illusion of pain.
The Thermal Grill Illusion

In 1896, Thunberg invented an apparatus that would open the door to a realm of research in thermal and pain processing. His apparatus consisted of two interlaced sets of coiled tubes arranged so that one would have cool water run through it and the other would have warm water run through it. Thunberg discovered that the simultaneous stimulation of the skin by these two temperatures produced an unusually hot sensation. Many years later, Craig and Bushnell (1994) concluded that this sensation of heat is accompanied by pain. This illusion of heat and pain produced by simultaneous warmth and cool came to be known as the thermal grill illusion (TGI).

The thermal grill has provided a great opportunity to study the interaction of innocuous thermal temperatures and pain. Because a painful sensation is felt using temperatures that are not painful individually, the combination of these thermal signals must be capable of contributing to the encoding of pain. It is also possible that one or both of the temperatures used in the thermal grill illusion are capable of stimulating nociceptors, but that this stimulation is masked during normal conditions. The mechanism and parameters by which this illusion is created are still under debate.

Parameters of the TGI

Many researchers have investigated the parameters that are important for generating the illusion, most using an apparatus consisting of parallel, interlaced sets of bars rather than the coiled bars originally employed by Thunberg. Neither the number of stimulation bars nor the distance between the bars significantly affects the occurrence of the thermal grill illusion (Defrin, Benstein-Sheraizin, Bezalel, Mantzure, & Arendt-Nielsen, 2008; Li, Petrini, Wang, Defrin, & Arendt-Nielsen, 2009). Defrin and colleagues (2008) sought to test the spatial boundaries of the
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thermal grill illusion using two probes that were spaced between 0 and 30 cm apart in various trials, rather than a cluster of alternating temperature bars. The results of the study revealed that a painful thermal grill illusion occurred at a distance of up to 30 cm apart, demonstrating that the temperatures can summate in and between dermatomes of the skin; areas supplied by only one spinal nerve (Kishner, 2013).

Temperature parameters of the thermal grill have been tested by Bouhassira, Kern, Rouaud, Pelle-Lancien, and Morain (2005). Using a traditional thermal grill apparatus of parallel copper bars, they tested individual pain thresholds of participants. Temperatures used in the thermal grill stimulation were never extreme enough to cause pain individually. Results of the study showed that the frequency and intensity of the thermal grill illusion are directly related to the magnitude of the difference between the warm and cool temperatures used. Temperatures tested ranged from 4-10°C above and below cold and heat pain threshold, respectively. It is clear that it is possible to produce the thermal grill illusion of pain under a variety of conditions; however, a temporal aspect of the illusion is one parameter that has yet to be tested.

Theories of the TGI

Specificity theory.

At the time of the TGI’s discovery, most researchers were strong proponents of Von Frey’s specificity theory of somatosensation (Green, 2004). Von Frey suggested that the skin contains distinct populations of sensory neurons that are each sensitive to only one form of stimulation (e.g. cold) and therefore would encode to the brain only one specific quality (e.g. coldness; Boring, 1942). The idea that these distinct modalities of temperature and pain could interact with one another was an unpopular view at the time.
Support for the specificity theory included the fact that there are numerous warm and cold spots on the skin. When a cold spot is stimulated with a cold stimulus, the resulting sensation is cold. However, Von Frey discovered that cold spots also paradoxically respond to hot temperatures, producing a sensation of cold (Boring, 1942). This discovery was thought to further support the specificity theory by demonstrating that activation of cold-spots on the skin always leads to a perception of cold, no matter the initiating stimulus (Boring, 1942).

Based on the paradoxical cold phenomenon, Alrutz (1898) proposed the first theory of the TGI. His theory suggested that the perception of heat was the result of simultaneous warm and cool sensations. Alrutz concluded that without cold spots only warm could be felt and without warm spots only cold could be felt. Therefore, only with warm and cold spots simultaneously activated could one experience the sensation of heat. According to Alrutz, this simultaneous experience of warm spots producing a warm sensation and cold spots producing paradoxical cold was the normal code for heat. Normally, when one feels a hot sensation, warm spots are being activated, and cold spots are also being activated in response to the heat, paradoxically producing cold. Therefore, he believed the thermal grill was synthetically producing the natural feeling of a hot sensation by activating both of these receptors at the same time. The discovery of the thermal grill illusion by Thunberg was important for Alrutz because Thunberg’s apparatus provided a way to demonstrate and support Alrutz’s theory; the first to attempt to explain how thermal and pain signals may be related to one another.

Though Alrutz’s theory laid the groundwork for future studies, a number of more recent theories have attempted to explain the mechanism behind the thermal grill illusion. Though some studies have suggested cognitive components of the thermal grill illusion (Kammers, de
Vignemont, & Haggard, 2010), others theorize that the important interaction occurs at the level of the spinal cord.

**Processing in the spinal cord.**

Research on neurons located in a sensory path beginning in the spinal cord known as spinothalamic tract (STT) demonstrated that the integration of thermal and pain signals is possible (Green, 2004). Though some STT neurons appear to be labeled lines as von Frey would have expected, some demonstrate multimodal characteristics that may explain the integration of warm and cool in the TGI. STT nociceptive-specific (NS) cells, for example, seem to respond as von Frey predicted. These cells respond only to painful stimuli such as heat or pinch (Craig, Krout, & Andrew, 2001). "WARM" and "COOL" neurons also appear in a sense to have labeled lines. "WARM" neurons respond monotonically to heating throughout the innocuous warmth range before plateauing and continuing to fire at noxious temperatures (Andrew & Craig, 2001). However, while the plateau does indicate that they cannot encode changes in hot temperatures, the fact that they continue to fire at noxious temperatures means they may still have some effect on the intensity or quality of heat and heat pain (Green, 2004). One type of STT cell that may contribute to the co-regulation of thermal and pain pathways are heat, pinch, cold (HPC) cells (Craig, Krout, & Andrew, 2001). These cells discharge to noxious cold, noxious heat, innocuous cool, and pinch (Craig, Krout, & Andrew, 2001). Wide dynamic range (WDR) neurons are another type of polymodal neuron that could be involved in the integration of thermal and pain signals because they are capable of receiving information from signals that encode mechanical stimuli as well as noxious and innocuous thermal sensations. (Price & Dubner, 1977). The discovery of these multimodal neurons was important because they demonstrate that not all
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pathways are labeled lines, and some neurons respond to various stimuli and therefore may allow different sensations to modulate one another or produce a variety of responses.

*Spinal addition theory.*

One of these theories suggesting that TGI results from spinal interactions across modalities is the “spinal addition theory.” The addition theory simply proposes that the combination of warm and cool together on multimodal neurons is enough to strongly activate those neurons, where each stimulus on its own would not. The strong activation produced by the combination of warm and cool may be similar to the strength of activation that occurs in response to normal heat pain, therefore producing a painful response. As mentioned above, Bouhassira et al. (2005) found evidence supporting this theory. Bouhassira et al. (2005) showed that the frequency and intensity of the pain created by the thermal grill illusion were directly related to the difference between the temperatures of the warm and cool stimuli, suggesting a simple addition. According to the spinal addition theory, the magnitude of ratings produced from the temperatures combined should be equal to the sum of ratings for each temperature on its own. Bach (2011) found support for the addition theory in that the sum of the ratings of the individual thermal stimuli was not significantly different from the thermal rating of the thermal grill stimulus. Additionally, Green (2002) found results supporting the addition theory in two experiments involving the thermal grill. Results from both experiments showed that perceived intensity at least doubled when warm and cool stimuli of similar intensity were combined.

*Disinhibition theory.*

Others believe that the TGI involves spinal interactions that are more complicated than simple addition. For example, Craig and Bushnell (1994) proposed the disinhibition theory,
which suggests that the painful heat evoked by the thermal grill is due to the unmasking of cold pain by warmth. According to the theory, normal activation of cold fibers results in an inhibition, or masking, of pain. Normal activation of warm fibers results in an inhibition of cold signals. Therefore, during simultaneous activation of warm and cold fibers, warm signals inhibit cool signals, which, in turn, results in a disinhibition, or unmasking, of pain signals. This theory was supported by their study which involved recording signals from cells in the spinal cords of anesthetized cats. Results demonstrated a reduction of activity in the cold channel during simultaneous exposure to warm and cool, and also a shift in the pattern of activity toward nociceptive channels.

Though the disinhibition theory is the most widely accepted at the present time, it may be incomplete. Craig and Bushnell (1994) presented the warm stimulus 5 s before the cool stimulus in their experiment based on Thunberg's (1896) idea that this produced a more salient illusion. However, this idea has never been formally tested. It is possible that the results produced by Craig and Bushnell (1994) are only applicable to the thermal grill illusion when warm is presented first. Different results may occur if cool precedes warm or if both temperatures are presented at the same time. Therefore, this aspect of the illusion should be formally tested.

**Purpose of the Present Study**

The present study will aim to test whether a temporal aspect of the thermal grill illusion does exist that would cause significant differences in the way the illusion is felt. In addition to the Craig and Bushnell (1994) study that assumed a temporal aspect did exist, another recent study failed to eliminate a temporal aspect as the cause of its results. Harper and Hollins (2014) conducted a study on adaptation and the thermal grill illusion. They aimed to determine whether
adaptation to warm, neutral, or cool would affect the way the thermal grill illusion was felt. Results indicated a significant decrease in pain caused by the thermal grill illusion following 3 minutes of adaptation to the cool temperature. However, pain ratings did not decrease following 3 minutes of adaptation to the warm or the neutral temperatures (Harper & Hollins, 2014). While Harper and Hollins (2014) demonstrated successful manipulation in regards to adaptation, it is still possible that temporal parameters are critical to the thermal grill illusion and that the results may have occurred because one stimulus began before the other.

In the current study I will test the temporal aspects of the TGI by offsetting the timing of warm and cool, while minimizing the possibility of adaptation. I hypothesize that when cool precedes warm, there will be a reduction in pain ratings, as was seen in the previous study. However, as opposed to being due to adaption, I hypothesize that this effect will occur due to the ability of the cool fibers to inhibit pain signals, and with cool preceding warm, it will have a larger inhibitory effect. Similarly, I hypothesize that when warm precedes cool, there will be a rise in pain ratings, since warm will have a greater ability to inhibit cool (thus disinhibiting pain).

There is reason to believe that a temporal aspect does exist. Aside from Thunberg’s (1896) belief that the thermal grill illusion is more salient when warm is presented before cool, the effect of temporal inhibition has also been observed in the visual system. When rods and cones are both stimulated, the signal that first reaches a ganglion cell has the best chance of producing excitation, and also leaves a transitory refractoriness following their signal (Gouras & Link, 1965). This study will be a formal test of whether or not there is a temporal effect of the TGI. If a situation similar to the one that occurs in the visual system does occur in the somatosensory system, not only will we have a better understanding of the TGI, but there may be
ways to modulate pain using thermosensory or other systems that could lead to better treatments for chronic pain and pain in general.

**Methods**

**Participants**

Twenty-four PSYC 101 students from the University of North Carolina at Chapel Hill participated in this study. Subjects were recruited using the participant pool website and they received one hour of credit toward their PSYC 101 class in return for participating. All subjects gave written consent. Six participants were male and 18 participants were female. Their ages ranged from 18 to 21 with an average age of 19 years. All procedures were approved by the IRB.

**Design**

A within subjects design was used for this experiment with all runs counterbalanced between subjects. The independent variable in this experiment was the temperature stimulus that preceded normal thermal grill stimulation, of which there were 3 different types. The 3 types of preceding stimuli were a warm stimulus (42° C), a neutral stimulus (32° C), and a cool stimulus (18° C). Normal thermal grill stimulation consisted of spatially alternating warm (42°C) and cool (18°C) temperatures. In the neutral first (NF) condition all bars were 32° C; however, during the warm first (WF) and cool first (CF) conditions, alternate bars contained either warm and neutral temperatures (42°C and 32°C) or cool and neutral temperatures (18°C and 32°C; Figure 1). In all three cases, the preceding stimulus period lasted only 15 s, too short a time for significant adaptation to occur. The dependent variable was the pain rating provided during normal thermal grill stimulation (i.e. 42° C interlaced with 18° C) via a computerized visual analog scale as well as responses to a sensation questionnaire.
Materials

Our lab’s thermal grill consisted of 12 copper bars laid out 0.75 cm apart. The copper bars were hollow in order to allow water to run through them to control their temperature. Cool temperature bars were 18° C, warm temperature bars were 42° C, and neutral bars were 32° C. These temperatures were chosen based on previous studies (Harper & Hollins, 2014).

Participants provided thermal and pain ratings during the experiment by using a mouse to manipulate a visual analog scale (VAS). The thermal VAS ranged from “coldest sensation imaginable” to “no thermal sensation” to “hottest sensation imaginable.” It ranged in value from -100 to 100 and ratings began in the middle on “no thermal sensation”. The pain VAS ranged from “no pain” on the left to “most intense pain imaginable” on the right and ranged in value from 0 to 100. Ratings for this scale began on “no pain.” Participants used the mouse to move a bar back and forth on the scale to signify what magnitude and type of sensation they were feeling. Participants were presented with the thermal VAS first and the pain VAS second. Ratings for both VAS scales were recorded continuously every tenth of a second.

Two questionnaires were also used in this experiment. A demographics questionnaire was given to all participants requesting information regarding age, gender, race, ethnicity, and handedness. A sensation questionnaire was also used in order to gather categorical data regarding what participants were feeling. The sensation questionnaire asked that the participant circle any and all of the sensations they experienced during the last few moments their arm was on the apparatus. They included thermal descriptors including warm, hot, cool, cold and neutral, as well as pain descriptors including burning, stinging, aching, and sharp.

Procedure
Participants reported to 104 Davie Hall for the experiment to take place. They began by giving informed consent and then filling out the demographics questionnaire. Next, participants performed a training session in order to learn how to use the VAS. The training session involved listening to a piece of classical music and rating the loudness on a VAS that ranged from “no loudness” on the left to “the loudest music imaginable” on the right.

After the training exercise, participants were shown a demo of the visual analog scales they would use during the actual experiment and were instructed how to place their arm on the apparatus. All participants were instructed to place the ventral side of their left forearm on the grill, perpendicular to the bars. They were told to center the grill about half way between their wrist and their elbow, making sure to make good contact with all twelve of the bars. The experiment consisted of three runs, each lasting just over 1 minute. For one run, the participant was seated in front of the thermal grill with the computer screen facing them and the mouse on their right. The participants saw a 5 second countdown and placed their arm on the thermal grill at the end of the countdown. They immediately began rating thermal sensation via the thermal VAS for 45 seconds and then viewed another 5 second countdown before rating pain for a final 15 seconds also via the pain VAS. Participants were instructed to keep their arm in place for the entire duration of the run. A timeline of one run of the experiment can be seen in Figure 2.

At the end of the run, participants removed their arm from the apparatus and completed a sensation questionnaire about their sensations in the moments before they removed their arm. Participants received a 15 minute break between runs. The next 2 runs were completed exactly the same as the first, with a 5 second countdown, 45 seconds of thermal ratings, another 5 second countdown, and 15 seconds of pain ratings. Participants filled out a sensation questionnaire after each of the 3 runs. They received another 15 minute break following their second run and they
were debriefed following the third run. The only variable that differed between each run was the temperature stimulus preceding normal thermal grill stimulation (warm, neutral, or cool). Normal thermal grill stimulation began at 15 seconds for all runs for all participants.

**Statistical Analysis**

Thermal ratings for the VAS scales were averaged in 5 second intervals throughout the 45 second thermal rating period for each run for each participant. Thermal ratings were evaluated to ensure that participants experienced the proper sensation during each part of the experiment; that is, negative ratings during the cool first run (CF), neutral ratings during the neutral first run (NF), and positive ratings during the warm first run (WF). Because cold ratings were recorded as negative and warm ratings were recorded as positive, absolute values of thermal ratings were used for statistical analysis, which allowed a comparison of magnitude rather than direction. Pain ratings for the VAS scales were also averaged in 5 second intervals for the 15 second pain rating period for each run for each participant. An average of the last 10 seconds of each participant’s thermal and pain ratings for each run was calculated for use in statistical analysis. These averages were used because the thermal VAS and pain VAS were both set to 0 at the start of the participant’s rating. Therefore, it took some time for the participant to get to and stabilize their ratings.

A within-subjects repeated measures ANOVA was run in order to determine if significant differences exist among pain ratings in the three runs. Results supporting my hypothesis would show significant differences between all three trial types. The WF run would have the highest average pain ratings, followed by NF pain ratings, followed by CF pain ratings. Sensation questionnaires were evaluated in order to determine if a similar across-condition pattern could be
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seen in the use of pain descriptors. According to my hypothesis, it was expected that WF trials would have the most pain descriptors, followed by NF trials, followed by CF trials.

Results

Data from 24 participants were analyzed. Thermal ratings during the first 15 seconds of each run demonstrate that participants felt the proper stimulus in each condition (e.g. warmth during the warm run); therefore, the manipulation of the initial temperature was successful as can be seen in Figure 3.

Effects on the Painfulness of the TGI

In order to determine if there was a temporal aspect to the thermal grill illusion, two measures of pain were utilized: sensation questionnaires and VAS pain ratings. The sensation questionnaire included descriptors for both thermal and pain sensations. The pain descriptors were stinging, burning, aching, and sharp. In order to determine if there was a difference in pain between conditions, the average number of pain descriptors circled for each run was compared. A within-subjects repeated measures ANOVA revealed that there were no significant differences between any of the groups $F(2, 23) = 0.940, p = 0.398$ (Figure 4). For the VAS ratings, only the average of the last ten seconds was used in order to allow time for the ratings to stabilize. Another within-subjects repeated measures ANOVA revealed that there were also no significant differences in the averages of the last ten seconds of pain ratings for each condition $F(2, 23) = 1.512, p = 0.234$ (Figure 5). Neither the sensation questionnaire nor the VAS ratings provided evidence that a temporal aspect of the thermal grill illusion exists that would lead to a difference in pain.

Ratings of TGI Thermal Intensity
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Thermal intensity ratings in response to the thermal grill were also recorded in this experiment, as synthetic heat is another aspect of the thermal grill illusion. On the VAS, warm ratings were recorded as positive values and cool ratings were recorded as negative values. Because some subjects reported warmth and cold in alternation, absolute values of thermal ratings were used in order to allow an overall response measure to be derived. A within-subjects repeated measures ANOVA showed that there were no significant differences in the average of the absolute value of the last ten seconds of temperature ratings for each condition $F(2, 23) = 3.142, p = 0.53$ (Figure 6). These results suggest that a temporal aspect does not exist that would lead to differences in synthetic heat or thermal intensity of the TGI.

Descriptions of TGI Sensations

Each descriptor on the sensation questionnaire was also analyzed in order to determine if there were differences among specific descriptors, rather than among thermal sensations and pain sensations in general. A graph of the results from the sensation questionnaire showed possible differences in ratings of cool, cold, and stinging between trials (Figure 7). Wilcoxon signed-rank tests were conducted to determine whether any of these differences were significant. There was one significant difference in reported cold sensations between the WF and CF trials $Z = -2.449, p = 0.015$; however, using a Bonferroni correction to correct for multiple comparisons, the value is no longer significant. None of the other differences were significant ($p > 0.10$, for all). Analysis of the sensation questionnaire suggest that no specific descriptors are affected by the temporal differences between conditions.

Discussion
Results from this study did not support the initial hypothesis. The hypothesis was that there was a temporal aspect to the thermal grill illusion such that when cool precedes warm, participants would report lower pain ratings, and when warm precedes cool, participants would report higher pain ratings. There were no significant differences in pain ratings between CF, WF, or NF conditions. There were also no significant differences in the magnitude of thermal ratings or in the sensation questionnaire responses between any of the conditions, suggesting that there is no thermal aspect to the thermal grill illusion.

Parameters of the TGI

These results are important because they suggest that the exact onset times of stimuli presented initially does not have a significant effect on the thermal grill illusion of pain, as long as pre-treatment is too short to allow substantial adaptation to occur. This idea had been presented by some researchers who noted a stronger illusion when the warm stimulus was presented first and therefore adjusted the timing of the stimuli in order to produce the “best” illusion (Thunberg, 1896; Craig & Bushnell, 1994). Results across studies that did and did not adjust for the exact timing of thermal stimuli are all comparable in terms of methods. In addition to the number of bars and spatial boundaries of the thermal grill, the temporal component is another aspect that does not affect the way the illusion is felt.

Theories of the TGI

The results of this study neither support nor oppose the spinal addition theory. Though the stimuli were timed differently, it is still possible that once the second stimulus was turned on, the signals converged with enough strength to activate a multimodal spinal cord neuron such as a WDR neuron that would result in pain.
As for the disinhibition theory, results from this study alone also do not allow for support or opposition to the theory. The results do suggest that the procedure demonstrated by Craig and Bushnell (1994) in which the warm stimulus preceded the cool stimulus by 5 s is not capable of producing a more intense thermal grill illusion like they thought. Furthermore, results from this study do suggest that a temporal aspect for the thermal grill illusion of pain is not a viable explanation for the results of the experiment conducted by Harper and Hollins (2014). Harper and Hollins conducted an experiment testing the effect of adaptation on the TGI. They found that adaptation to the cool stimulus, and not to warm or neutral stimuli, resulted in significantly lower average pain levels. The results of the present experiment show that the effect seen in the study conducted by Harper and Hollins (2014) did not occur simply because the warm stimulus preceded the cool stimulus, but did in fact occur due to adaptation. The fact that significantly less pain was felt following adaptation to only the cool stimulus suggests that the cool stimulus is directly related to the painful sensation.

Future studies should aim to further investigate the role that the cool stimulus plays in the thermal grill illusion of pain. It is clear that the cool stimulus plays a crucial role in the sensation of pain created by the TGI. It is important to continue studies involving the thermal grill illusion of pain because they show great potential for insight into how thermal and pain processes interact. Research involving the thermal grill may someday suggest a way to diagnose and/or treat central pain.
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Figure 1. This figure represents the three pre-stimulus conditions of the experiment as well as thermal grill stimulation as it was presented on the apparatus. CF represents the cool first run, with bars alternating 18 and 32°C. WF represents the warm first run with bars alternating 42 and 32°C. NF represents the neutral first run with all bars 32°C. Thermal grill represents thermal grill stimulation in which bars alternated 18 and 42°C.
Figure 2. Timeline of one experimental run. Each participant completed this timeline time for each of three conditions. Following completion of the timeline participants filled out a sensation questionnaire and took a 15 minute break before completing the next run.
Figure 3: This graph demonstrates that participants felt the proper stimulus during the initial portion of the experiment for each condition. Cool temperatures were recorded as negative values and warm temperatures were recorded as positive values. The black line represents the time thermal grill stimulation was turned on. This graph includes data from all 24 participants.
Figure 4. Average number of pain words circled among all participants for each of 3 conditions. There were a total of four pain words that could have been circled. They were aching, burning, stinging, and sharp. Differences between these groups were not significant \((p > 0.10\) for all).
Figure 5. Average pain ratings during last ten seconds of thermal grill stimulation. The differences between these ratings were not significant ($p > 0.10$).
Figure 6: This graph shows a comparison of the average magnitude of the last 10 seconds for all 24 participants in each of 3 conditions. There were no significant differences between these 3 conditions ($p > 0.10$ for all).
Sensation Questionnaire Responses for Thermal Grill Stimulation

Figure 7. Sensation questionnaire responses based on percentage of total participants. None of these differences were significant ($p > .05$ for all).