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Superficial Cold And Heat Application During Transcutaneous Electrical Stimulation May Not Change Perceived Sensation Of Pain

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Abstract

Transcutaneous electrical stimulation is commonly applied in clinical practice to provide pain relief. Due to the discomfort associated with high intensity electrical stimulation, cold or heat is often applied to the area to allow higher stimulus intensity based on suggestions that the application of cold or heat alters the sensory pain perception through sensory nociceptive pathways. It is therefore of clinical relevance to investigate whether application of superficial heat or cold changes perceived pain sensation as a function of stimulation threshold. Twenty-six participants volunteered for this study. Constant voltage electrical stimulation with a frequency of 5 Hz, and a pulse width of 300 microseconds was applied to the tibialis anterior. The intensity of the electrical stimulation varied from zero to 200 volts peak to peak. Participants were requested to state when they first perceived any sensation of the electrical stimulation and when stimulus intensity became intolerable. Paired t-test analysis indicated no significant difference in the baseline peak current and the peak current following the application of either superficial heat or cold at the sensory threshold or limit of tolerance. There was a significant difference in the plateau current at baseline compared to the plateau current following the application of superficial heat and cold at the sensory threshold and limit of tolerance. From the experimental results this finding appears to be an artefact of altered skin impedance resulting from changing skin temperature. Thus, it is unlikely that the application of superficial heat or cold significantly changes the way transcutaneous electrical stimulation normally interacts with the sensory or pain systems.

INTRODUCTION

Transcutaneous electrical stimulation is commonly applied in clinical practice to provide pain relief.(Van Swearingen, 1999) However sensory perception including discomfort and pain often accompanies subcutaneous electrical stimulation (Low and Reed, 2000; Van Swearingen, 1999) and although extended analgesia is sometimes advantageous, the pain associated with sensory fibre activity frequently makes high intensity electric stimulation intolerable.(Walsh, 1997) Electrical stimulation applied in combination with the simultaneous application of superficial heat or cold may reduce perceived pain and pain thresholds. However limited evidence is available on how these modalities interact with one another and whether there is any benefit. This research project investigated the interaction between superficial cold and heat and transcutaneous electrical stimulation, when these modalities are combined under experimental conditions.

SUPERFICIAL COOLING

Superficial cooling decreases skin temperature rapidly and involves the application of a cooling agent such as ice, cold gel packs, ethylchloride or other cooling sprays to the skin surface, and immersion in a cold water bath.(Ernst and Fialka, 1994; Johnson et al., 1989) An early study on the effect of skin temperature had no effect on subjective sensory sensation when a finger was electrically stimulated (0.2msec, 1Hz) at baseline skin temperature and again after the application of a cold water bag to 17^{o}C threshold.(Todnem et al., 1989) Whereas other reports using superficial cold application suggested the opposite.(Bugaj, 1975; Ernst and Fialka, 1994) However pain increases linearly with decreasing skin temperature and is consistently perceived at temperatures below 0^{o}C.(Chen et al., 1996; Simone, 1997)

SUPERFICIAL HEAT

Skin temperature increases rapidly following the application of a superficial heat source. The effect of superficial heat on perception and subjective sensory thresholds to transcutaneous electrical stimulation respectively has been examined with results showing no significant effect with increased temperature.(Hawkes, 1962; Todnem et al., 1989) Innocuous heat is widely used clinically for analgesic purposes.(Low and Reed, 2000; Williams et al., 1986) As the temperature rises above 43°C, superficial heat is no longer perceived as warmth, but has a burning or painful quality.(Konietzny, 1984)

Superficial heat has previously been applied simultaneously with painful electrical stimulation at a site distant to the application of electrical stimulation. The effect of superficial heat whilst stimulating the right peroneal nerve demonstrated a reduced sympathetic skin response which has a relationship with subjective pain thresholds.(Yagiz On et al., 1997) Results obtained from insertion of electrodes into cutaneous fascicles of the median nerve at the wrist of four participants and then increasing the skin temperature in the region to 40°C with a heat lamp was inconsistent, with two participants reporting mild to moderate pain relief, while the other participants did not experience any pain relief. (Bini et al., 1994) It is unclear what effect superficial cold will have on the sensory threshold to electrical stimulation when the skin temperature is decreased below 17°C or what effect superficial heat will have on the limit of tolerance to electrical stimulation.

METHOD

Twenty six participants (7 males and 19 females) volunteered for this study and were informed about the procedure and the potential risks of the study prior to volunteering. All participants gave written informed consent. The study was approved by the Charles Sturt University Ethics in Human Research Committee (Protocol number 02/175). Participants were excluded if they had known previous adverse reaction to electrical stimulation, superficial cold or superficial heat. The presence of a cardiac pacemaker or other implanted electrical device, any open wound or skin lesion in the region to be electrically stimulated as well as infection, joint injury or deep venous thrombosis in the limb to be stimulated led to exclusion. Participants were also excluded if they had deficient tactile or thermal sensation determined by a Semmes-Weinstein monofilament sensation test, and a hot/cold sensation test. A repeated measures design was used in this study.

Initially, participants were in a supine position, with their lower leg fully exposed and their ankle resting in a comfortable position. The motor point of the tibialis anterior was located and large rectangular electrode (100 x 55mm) secured to the skin surface with a thin layer of crepe bandage, a distance at least equal to the length of the electrodes (100mm) apart. A skin temperature probe was additionally secured adjacent to the electrodes under a single layer of crepe bandage. Constant voltage electrical stimulation (Forte™ CPS 200 Stim) with a frequency of 5 Hertz (Hz), and a pulse width of 300 microseconds (us) was applied to the tibialis anterior independent of another modality. The intensity of the electrical stimulator was slowly turned up from zero to a maximum 200 volts peak to peak. Participants were requested to state when they first perceived any sensation of the electrical stimulation and say 'stop' when they felt that they could no longer tolerate the stimulus, at this point the electrical stimulator was immediately turned off. The intensity readout from the output display of the electrical stimulator was recorded at each of these occurrences. Both the participant and investigator were blinded to the output display of the electrical stimulator during the recording of these thresholds. The skin temperature displayed on the digital readout from the superficial skin temperature probe was recorded at the commencement of each application of electrical stimulation. The sensory threshold and limit of tolerance was recorded three times under baseline conditions, with a one-minute break between each application. Three applications were used during this stage to allow an analysis of compound symmetry, which has been identified as an essential requirement for a repeated measures analysis.(Munro, 1997)

Throughout this study the leads of the electrical stimulator were placed in series with a 318 Ohm resistor and a cathode ray oscilloscope to allow measurement of the voltage drop across the sense resistor at this test voltage displayed on the oscilloscope screen. The height of the stable current flow was recorded and enabled the calculation of the current (plateau) using the known voltage and resistance values. The superficial skin temperature at the time the trace was measured was also recorded.

With the electrodes in place, an ice-water bag was applied over the electrodes and surrounding skin surface. Throughout this application the skin temperature was monitored, and allowed to decrease to a minimal temperature of 10°C. Once the skin temperature reached either 10°C or the decrease in skin temperature reached a plateau (average temperature 12.9°C; range 10.0-19.2°C), the electrical stimulation was reapplied with the same method as in stage one. The superficial cold source remained over the electrodes and surrounding skin surface when the electrical stimulation was applied. This facilitated the skin temperature remaining relatively stable (change <1°C) throughout the application of the electrical stimulation. Participant's sensory threshold and limit of tolerance was recorded once during this stage as it was difficult to maintain a stable temperature for the duration required to take multiple measurements. Additionally, pilot data analysis and previous investigators (Laitinen and Eriksson, 1985) have revealed high repetition within individual participants. The measurement from the cathode ray oscilloscope was repeated using the same voltage level as stage one (providing the voltage recorded for limit of tolerance during this stage continued to fall within an accepted voltage range). The superficial skin temperature was again recorded when this measurement was taken.

After sufficient time, a heat pack from a thermostatically controlled hydrocollator was applied on several layers of toweling over the electrodes and surrounding skin surface. Toweling was used to ensure that the sensation perceived by participants was comfortable warmth. Throughout this application the skin temperature was monitored, and allowed to reach a maximum temperature of 42°C. Once the skin temperature reached either 40°C or the skin temperature reached a plateau (average 39.4°C, range 37.6 - 41.4°C), the electrical stimulation was reapplied with the same method as stage one. The heat pack remained in place during application of the electrical stimulation, and participant's sensory threshold and limit of tolerance was recorded only once as was the cathode ray oscilloscope record using the same voltage level as stage one (providing the voltage recorded for limit of tolerance during this stage continued to fall in an accepted voltage range). The superficial skin temperature was again recorded when this measurement was taken. An alpha interclass correlation (ICC) using SPSS (version 14) was used for a reliability analysis of the sensory thresholds and limit of tolerance at baseline.

STIMULUS REPRESENTATION DURING DATA ANALYSIS.

During this study a fixed voltage pulse of electricity was applied to the skin surface. This resulted in a pulse of current with an initial spike, a plateau, and a certain amount of charge being delivered through the skin surface, Since the application of a pulse of fixed voltage produces a pulse of current with these characteristics, the stimulus may by quantified by each of these features.

THRESHOLD COMPARISONS

The peak current and the current at plateau were used to quantify the stimulus for this study. In terms of temperature dependence these two methods represent the stimulus at threshold very differently. At one end, the peak current is independent of temperature. At the other end, the plateau current is significantly dependent on temperature. Although neither of these methods represents the intensity of the stimulus in an ideal way, each method contributes information to the representation of the stimulus. For this reason a paired t-test (Statistical Package for Social Sciences, SPSS Version 14), was used to analyse the differences for peak current and the current at plateau.

RESULTS

RELIABILITY ANALYSIS

Analysis using alpha interclass correlation (ICC) revealed that the three measurements taken at baseline were significantly correlated; sensory threshold (□ = 0.9919, p<.001), and limit of tolerance (□ = 0.9860, p<0.001).

PEAK CURRENT

Analysis using a paired t-test indicated that there was no significant difference in the baseline peak current and the peak current following the application of either superficial heat or cold at the sensory threshold or limit of tolerance (Table 1).

Figure 1

Table 1. Peak Current - Mean difference and paired t-test

Condition	Mean difference (mA)	T Statistic	Significance (2-tailed)
Sensory Threshold			
Baseline/Cold	0.486	-1.172	0.252
Baseline/Heat	0.263	-0.381	0.706
Limit of Tolerance			
Baseline/Cold	-3.239	1.527	0.139
Baseline/Heat	0.006	-0.004	0.997

PLATEAU CURRENT

There was a significant difference in the plateau current at baseline compared to the plateau current following the application of superficial heat and cold at the sensory threshold and limit of tolerance (Table 2). The mean plateau current increased following the application of superficial heat at the sensory threshold and limit of tolerance. The mean plateau current decreased following the application of superficial cold at the sensory threshold and limit of tolerance.

Figure 2

Table 2. Plateau Current - Mean difference and paired t-test

Condition	Mean difference (mA)	T Statistic	Significance (2-tailed)
Sensory Threshold			
Baseline/Cold	-0.459	2.654*	0.014
Baseline/Heat	1.123	-4.840***	<0.001
Limit of Tolerance			
Baseline/Cold	-4.136	4.539***	<0.001
Baseline/Heat	7.287	-9.601***	<0.001

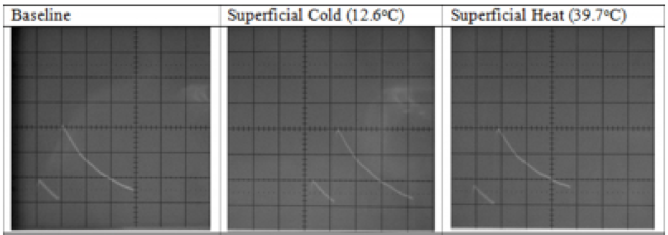
*p<.05. **p<.01. ***p<.001.

DISCUSSION

During this study the peak and the plateau current were used to quantify the intensity of the stimulus current that was used to stimulate the sensory component of the tibial nerve. Although neither of these methods represents the current in an ideal sense, both were used as each contributes valuable information to the representation of the stimulus. The mean plateau current decreased following the application of superficial cold by 10.2% at the sensory threshold, and by 12.0% at the limit of tolerance, and increased following the application of superficial heat by 22.5% at the sensory threshold, and 21.4% at the limit of tolerance. Skin impedance is documented as one of the primary factors limiting current flow when moderate voltages are applied across the skin surface.(Reilly, 1998) Decreasing the skin temperature increases the skin impedance, while increasing the skin temperature decreases the skin impedance.(Gerleman and Barr, 1999) This would explain why in percentage terms the plateau current changed by a similar margin at each threshold for each thermal condition (fig 1). It appears likely therefore that the change in plateau current following the application of superficial cold and heat was primarily the result of altered skin impedance.

Figure 3

Figure 1. The current response to 50 volts (peak to peak) applied at baseline, and following the superficial application of cold and heat



Baseline	Superficial Cold (12.6°C)	Superficial Heat (39.7°C)
1. Peak Current 20V* **I = 50.37mA**	20V **I = 50.37mA**	20V **I = 50.37mA**
2. Plateau 1.5 divisions x 5 volts/div = 7.5 Volts **I = 7.08mA**	1.3 divisions x 5 volts/div = 6.6 Volts **I = 5.48mA**	1.6 divisions x 5 volts/div = 8.3 Volts **I = 8.67mA**

* 1 division = 5 Volts; I determined from I = V/R; V = Volts; I = current

Thus the application of superficial cold or heat does not significantly change the way transcutaneous electrical stimulation normally interacts with the sensory or pain systems. This is in keeping with the earlier findings where no significant difference was observed in the subjective sensory threshold to electrical stimulation when the skin temperature was decreased to 17°C, and the current required for the sensory threshold remained within 10% of baseline when the skin temperature was increased to a maximum of 45°C.(Hawkes, 1962; Todnem et al., 1989) It is possible that these authors also used a constant voltage electrical stimulator and that this small change in current resulted from changes in skin impedance.(Hawkes, 1962) These findings also clarify that further decreases in the skin temperature to approximately 10°C do not significantly change the sensory threshold to transcutaneous electrical stimulation.

Although the application of painful superficial cold has been associated with a decrease in the threshold for perceiving any sensation of pain,(Notermans, 1966; Riley and Levine, 1998) this modality does not appear to affect the limit of tolerance to transcutaneous electrical stimulation in our study, when non-painful superficial cold was applied. The previous literature regarding the effect of superficial heat on the limit of tolerance is limited and it is unclear why there was no change in the limit of tolerance following the application of superficial heat in our study.

STUDY LIMITATIONS

The application of superficial heat or cold did not significantly change the sensory threshold or the limit of tolerance to transcutaneous electrical stimulation, it is unclear if the simultaneous application of these modalities changed the sensory perception of the electrical stimulation throughout its application. Additionally, it is unclear what effect the simultaneous application of these modalities had on the way the superficial thermal modality was perceived. This is significant from a safety perspective as the simultaneous application of electrical stimulation may alter an individual's ability to determine the intensity of a superficial thermal agent. Previous literature indicates that this may be the case as the threshold for detecting the slightest increase or decrease in skin temperature has been previously reported to increase during and after the application of electrical stimulation.(Ekblom and Hansson, 1987; Eriksson et al., 1985)

CONCLUSION

The effect of superficial heat and cold on the sensory threshold and limit of tolerance to transcutaneous electrical stimulation when these modalities are simultaneously applied was established. This study captured information relating to the peak and plateau current. The statistically significant difference in the plateau current at the sensory threshold following the application of both superficial cold and heat relative to baseline conditions appears to be an artefact of altered skin impedance resulting from changing skin temperature. Thus, it is unlikely that the application of superficial heat or cold significantly changes the way transcutaneous electrical stimulation normally interacts with the sensory or pain systems.

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