Effect of Variation in the Burst and Carrier Frequency Modes of Neuromuscular Electrical Stimulation on Pain Perception of Healthy Subjects

The purpose of this study was to explore the effect of various combinations of burst and carrier frequencies of neuromuscular electrical stimulation (NMES) on subjects’ perception of pain intensity associated with induction of high intensity muscle contractions. Twenty-seven healthy volunteers completed the study. After the initial test session, all subjects were treated in three additional sessions with nine combinations of burst frequencies (50, 70, and 90 bursts per second [bps]) and carrier frequencies (2,500, 5,000, and 10,000 Hz) at an NMES amplitude that produced torque equivalent to 50% of maximal voluntary contraction of their quadriceps femoris muscle. Subjects rated each frequency combination for perceived pain intensity with a visual analog scale. The combinations of burst frequencies (50, 70, and 90 bps) and carrier frequencies (2,500 and 5,000 Hz) do not differ from each other in perceived pain intensity but do differ significantly in perceived pain from the combinations of burst frequencies at the carrier frequency of 10,000 Hz. Thus, the clinician may have to try different stimulus combinations on patients at different current training levels to obtain the least individually perceived pain. [Rooney JG, Currier DP, Nitz AJ. Effect of variation in the burst and carrier frequency modes of neuromuscular electrical stimulation on pain perception of healthy subjects. Phys Ther. 1992;72:800–809.]

Key Words: Electrotherapy, electrical stimulation; Muscle performance, lower extremity; Pain.

Use of neuromuscular electrical stimulation (NMES) to develop muscle strength (torque, force), to improve athletic performance, and to increase muscle size has led to intensified research interest in this modality as a rehabilitative and muscle performance enhancing tool.1–11 Claims attributed to Kots of 100% increases in torque of untrained healthy subjects and 40% increases in torque of trained athletes served as the impetus for much of these investigations.3

Although training effects (increasing torque) have been achieved using NMES with training intensities ranging from 25%12 to 91%9 of maximal voluntary contraction (MVC), many researchers5,6,8,12 have proposed that volitional exercise intensities between 50% and 100% of the MVC are most effective for increasing torque.13 For example, Lai and coworkers12 showed that subjects training with NMES at 50% of MVC had higher gains of knee
extensor torque than did those using NMES of only 25% of MVC. Muscle contractions induced by NMES at these intensities, however, are hindered by subject perception of pain associated with the stimulus, and this is the major limitation to its clinical use for strength training.

Investigators have found that they could vary subjects' perception of pain by varying the current frequencies or waveforms of the carrier wave used for electrical stimulation. Vodovnik and coworkers found less pain with the use of sine-wave frequencies greater than 500 Hz, whereas Crochetiere and associates, using a square wave, found frequencies of 300 pulses per second (pps) to be most comfortable. Wong reported that twin-peaked monophasic pulses were less painful than asymmetrical biphasic pulses. Delitto and Rose could not find subject preference for three different waveforms (sine, sawtooth, and square) using current characteristics of 2,500 Hz, 50 pps, and 10 milliseconds' pulse duration. Baker and coworkers found subject preference for symmetrical biphasic square waves (32 pps) over sine waves at a 2,500-Hz frequency enveloped into 10-millisecond packages presented 50 times per second.

Kots stated that in order for NMES to be effective, the stimulus must produce a relatively low pain level and the current must be of adequate magnitude and frequency to produce high intensity tetanic muscle contractions. Moreno-Aranda and Seireg used an NMES unit that meets these pain and contraction requirements by delivering sine-wave stimuli at frequencies of 2,000 to 10,000 Hz. In order to produce maximum muscle contractions, they modulated (interrupted) the carrier frequency between 10 and 500 times per second. This base pulse rate was called a "carrier frequency" in that article (frequency of pulses within a burst), and the modulated carrier frequency was called a "burst." Bursts are finite series of pulses having fixed amplitude, duration, and rate (Fig. 1). Moreno-Aranda and Seireg reported that modulated carrier frequencies of 2,500 to 5,000 Hz produced considerable torque and that frequencies of 9,000 and 10,000 Hz were associated with the least subject pain.

Kots reported muscle contraction forces greater than voluntary contractions by using NMES with a modulated current that produced relatively little pain. Kots may also have considered the effect of tissue impedance on subject comfort when using 1,000 Hz and then changing to a 2,500-Hz carrier frequency. By increasing the frequency (reducing phase duration) of the NMES, the tissue opposition to current flow decreases to improve comfort. Kots probably believed that the problem of high intensity muscle contractions accompanied with pain was resolved by using a combination of burst frequencies (eg, 50, 70, and 90 bursts per second [bps]) and carrier frequencies (eg, 2,500, 5,000, and 10,000 Hz). The number of bursts per second, however, is physiologically the same as the number of monophasic or biphasic pulses per second in producing muscle contractions.

The form of current used by Kots has been referred to as "Russian" current or technique and consists of a continuous sine-wave output of 2,500 Hz (serving as a carrier frequency) modulated to provide bursts, each of 10 milliseconds' duration, separated by interburst intervals of 10 milliseconds. Several NMES units are marketed that produce "Russian" current, and some units permit physical therapist selection of burst and carrier frequency combinations for clinical use. Studies comparing combinations of burst and carrier frequencies are lacking in the literature. Information enabling proper selection of burst and carrier frequencies for effective patient management is needed. The purpose of this study was to ascertain the effect that various combinations of burst and carrier frequencies have on subjects' perception of pain intensity, while NMES produced a constant level of muscle torque. We expected to find a specific frequency combination (nine combinations of three burst frequencies and three carrier frequencies) to be best.

**Figure 1.** Burst and carrier frequency concept: (A) Continuous sine waves set at a specific carrier frequency (in hertz). (B) Bursts (in bursts per second), with the set carrier frequency within each unit, and interburst interval.
Table 1. Descriptive Data of Subjects (N=27)

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Weight (kg)</th>
<th>Height (cm)</th>
<th>Age (y)</th>
<th>Torque* (N·m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>71.5</td>
<td>176.0</td>
<td>22.0</td>
<td>269.6</td>
</tr>
<tr>
<td>SD</td>
<td>9.4</td>
<td>7.3</td>
<td>2.2</td>
<td>35.9</td>
</tr>
<tr>
<td>Range</td>
<td>54.5–93.1</td>
<td>160.0–193.4</td>
<td>18.0–35.0</td>
<td>146.4–244.0</td>
</tr>
</tbody>
</table>

*Knee extension torque (maximal voluntary contraction).

Method

Subjects

Twenty-seven healthy volunteers (22 men, 5 women), ranging between 18 and 35 years of age, participated in the study. The volunteers responded to announcements requesting subjects for the study. Subjects had no history of injury or known pathology of their knees and no previous experience with NMES. All subjects consented to participate in this study. Descriptive data of the subjects are shown in Table 1. All subjects in the study were able to accept sufficient NMES to cause 50% of their MVC and volitionally contract their quadriceps muscles during the test portion of the session. Subjects' maximum isometric extensor torque of their nondominant knee (chosen arbitrarily) was determined using a Cybex™ II dynamometer system.™ Torque calibrations with the chart recorder set on damp 3 were performed on a regular basis.

Each subject was seated on the dynamometer chair with the backrest inclined to 60 degrees and the tested knee fixed at 60 degrees of flexion. This position has been shown to be useful for yielding maximum torques.27,28 Body stabilization was provided during the torque determinations by a lap seat belt and by thigh and ankle straps, while subjects grasped the handles along the sides of the test chair. The axis of rotation of the dynamometer was aligned with the tested knee, and the dynamometer speed selector was set at 0°/s.

Subjects were asked to perform three consecutive isometric MVCs, each lasting about 3 seconds. The resultant torques were transcribed by a chart recorder. The highest peak torque reading of the three voluntary contractions was used as the MVC and for further analysis. Next, each subject was given sufficient time to become familiar with NMES while remaining seated on the dynamometer chair.

An ElectroStim 180-2i unit™ was selected for the "Russian" current because it is commonly used clinically, can be used to produce ample torque,29 and was developed to improve subject comfort.39 This NMES unit delivers individual sine waves at variable carrier frequencies (2,500, 5,000, and 10,000 Hz) and burst frequencies (50, 70, and 90 bps). An example of current output characteristics is a 2,500-Hz carrier frequency (200-microsecond phase duration) modulated to deliver 50 bps, with each burst lasting 10 milliseconds and with bursts separated by interburst intervals of 10 milliseconds.14 One of two surface stimulating electrodes (12×8-cm carbonized rubber) was placed longitudinally on the subject's skin over the femoral triangle, and a similar electrode was placed over the vastus medialis muscle.™ Sponges moistened with tap water and placed between the skin and the electrodes (commonly used clinical method) served as a mean-impedance conducting medium. Prior to stimulation, the electrode/skin impedance was recorded6 to test the quality of the electrode attachment and skin preparation. An impedance level of less than 50,000 Ω was considered arbitrarily acceptable to proceed with the NMES testing. Electrodes were strapped securely to the thigh by elastic wraps.

Subjects were instructed to control the stimulus and time for their left knee extensors to produce a torque equivalent to 50% of their predetermined MVC, and to avoid volitional contraction of their quadriceps femoris and hamstring muscles during NMES. The tester (JGR) constantly observed these muscles and the shape of the torque curves for any tendency to volitionally contract them and to ensure 50% of MVC by NMES on all contractions.

Procedure

Initial session. In the initial session, the subjects' height, weight, and age were recorded. Then subjects were familiarized with the test equipment and procedure. After familiarization, 5 minutes of rest to avoid fatigue was given each subject before engaging in the test portion of the session. Subjects' maximum isometric extensor torque of their nondominant knee (chosen arbitrarily) was determined using a Cybex™ II dynamometer system.™ Torque calibrations with the chart recorder set on damp 3 were performed on a regular basis.

Experimental sessions. Following the initial test session, three experimental sessions (sessions 2, 3, and 4) were held, with a 1-week interval between sessions. Each experimental session consisted of three NMES treatments. A treatment consisted of 10 muscle contractions at 50% of MVC, induced by NMES that delivered a randomly selected burst and carrier frequency combination (eg, 50 bps/
5,000 Hz). Each induced contraction lasted 15 seconds (5-second ramp on) followed by a 50-second rest (23% duty cycle). Stimulus amplitude was adjusted by the tester about every two contractions to maintain torque at 50% of MVC (amplitude increased 6-20 mA over initial level). A treatment set of 10 induced contractions was followed by a 5-minute rest period, a period we believed to be sufficient to recover from any muscle fatigue. This treatment sequence was then repeated two more times per experimental session with different randomly selected combinations of burst and carrier frequencies. An experimental session of three NMES treatments lasted 30 to 45 minutes (7.5 minutes of NMES), and the three experimental sessions (2, 3, and 4) involved a total of nine burst and carrier frequency combinations.

In the 5-minute rest period following the 10th induced contraction of each set of frequency combinations, the subjects rated their perceived pain intensity using a visual analog scale (VAS), a 10-cm horizontal line. The 10-cm line was labeled “no pain” at 0 (left end) and “pain as bad as it could be” at 10 cm (right end). The VAS provides a ratio-level measurement that is reproducible and correlates with other methods of measuring pain. Twelve subjects were randomly selected in the initial session to rate their pain with a VAS after random measurements administered to assess the reliability of the instrument when measuring pain associated with NMES. A random model for intraclass correlation provided a coefficient of .954. The time selected for administering the VAS negated recall or bias toward the current frequency combinations used in the study.

### Data Analysis

The VAS was arbitrarily divided into low and high ratings by dividing the 10-cm line into halves. The frequencies of subject ratings occurring in the left half were counted to indicate the number of times a burst and carrier frequency combination was rated as most comfortable.

Descriptive statistics (mean, SD) were calculated for demographic and recorded scores. Analyses of variance for repeated measures (burst/carrier frequency) were used to analyze the VAS and peak current (milliamperage) data. An alpha level of .05 was used in the analysis. The Duncan post hoc analysis was used to test all pairwise means when significant F ratios occurred. Relations between milliamperage (read from the NMES unit meter) and pain intensity ratings were determined by the Pearson Product-Moment Correlation method.

### Results

Table 2 discloses that combinations of burst frequencies (50, 70, and 90 bps) and carrier frequencies (2500, 5000, and 10000 Hz) significantly influenced the pain intensity ratings of subjects receiving NMES in this study. All burst combinations with carrier frequencies of 2500 and 5000 Hz led to significant differences in pain from the burst combinations with the carrier frequency of 10000 Hz. No statistical significance was found between the pain for combinations of burst frequencies (50, 70, and 90 bps) and carrier frequencies of 2500 and 5000 Hz. Figure 2 illustrates the trend of decreasing pain intensity ratings as the burst rate increased and of increasing pain intensity ratings as the carrier frequency increased in rate.

### Discussion

In addition to information revealed by the VAS data, the symmetry and consistency of torque curve patterns was disrupted by the burst combinations with the carrier frequency of 10000 Hz. Figure 3 shows that the 10000-Hz carrier frequency imposed the appearance of unfused tetanic muscle contractions on top of the recorded torque curve.

There was a marked variation in individual pain intensity ratings ranging from 0.2 to 9.6 cm on the VAS. The frequency of subjects selecting a burst and carrier frequency combination on the VAS on the left, or “no pain,” end of the scale showed that 18 subjects selected the 2500-Hz carrier frequency and 9 subjects selected the 5000-Hz carrier frequency. No subject selected bursts of the 10000-Hz carrier frequency (Tab. 3).

Peak current to produce the muscle contractions at 50% of MVC was consistently similar among burst combinations with a specific carrier frequency. Mean milliamperage among the combined bursts (50, 70, and 90 bps grouped together) with specific carrier frequencies of 2500, 5000, and 10000 Hz were significantly different (F=83.42, df=8 and 208, P<.001). Post hoc analysis revealed that combined bursts with 2500 Hz (X=35.4, SD=8.11 mA) differed from combined bursts with 5000 Hz (X=43.4, SD=10.44 mA) and 10000 Hz (X=19.7, SD=2.99 mA). The combinations also differed between carrier frequencies of 5000 and 10000 Hz. Correlations between milliamperage used to induce torques equivalent to 50% of
Means and standard error of means for combined effect of burst frequencies (in bursts per second [bps]) and carrier frequencies (in hertz) on subjective pain intensity rating.

MVC and pain intensity ratings of subjects ranged from −.13 to .33.

Approximately 50% of the subjects reported delayed onset of muscle soreness 24 to 48 hours following at least one stimulation session. These reports were given by subjects throughout the study.

There was no single combination of the nine burst and carrier frequency combinations that was optimal for producing strong muscle contractions while perceived to be less painful than others. This finding was unexpected. Burst combinations with carrier frequencies of 2,500 and 5,000 Hz did not result in differences in pain intensity. The burst combinations with the carrier frequency of 10,000 Hz were significantly more painful than the burst combinations with a carrier frequency of either 2,500 or 5,000 Hz.

The explanation for this reversal of the pain/frequency concept may lie in part in the “jerking” sensation (i.e., unfused tetanic-appearing contraction response) reported by all the subjects tested with the 10,000-Hz carrier frequency. The muscle contractions caused by this carrier frequency may also have caused increased subject apprehension. Several subjects commented that “it felt like my muscles were tearing.” This apprehension caused several subjects to attempt contractions of their hamstring muscles in order to alleviate the jerking motion and pain. As the attempts by some subjects to voluntarily contract the hamstring muscles were immediately discouraged by the tester, the brief contractions were not considered contributory to the recorded “jerking” torque waveforms. Perhaps the 10,000-Hz carrier frequency with the least amount of effective current and pulse charge among the tested carrier frequencies did not adequately excite as many motor units, especially the deeper ones, thereby restricting the muscle from going into fused tetany. Perhaps the damp setting of the torque recorder used to calibrate the dynamometer and record torque smoothed twitchlike contractions to give the appearance of a jerking motion or unfused tetany. This observation of torque curves associated with an appearance of unfused muscle tetany needs further investigation.

When further examining the data of pain intensity responses to the nine burst and carrier frequency combinations, certain trends were observed. As the rate of bursts increased, the pain intensity decreased, and subjects also reported more pain as the carrier frequencies increased. The phase duration of the carrier frequency of 10,000 Hz is 50 microseconds, which is shorter than the phase duration with either 2,500 and 5,000 Hz. Others have reasoned that subject comfort improves with very short
As pain-conducting nerve fibers are believed to be more superficially located than motor fibers, the stimulation by the carrier frequencies (eg, 2,500 Hz) is believed to minimize pain fiber stimulation, in spite of the greatest current density being located directly beneath each stimulating electrode. Researchers, using different or similar stimulus characteristics than those of this study, reported a decrease in painful sensory response as the frequency of the stimulation increased. Our finding of burst and carrier frequency combinations does not follow that reported observation. That is, as the carrier frequencies increased from 2,500 to 5,000 to 10,000 Hz in our study, subjects perceived the higher frequencies as more painful.

The pain intensity ratings reported in this study ranged considerably, with subjects marking the VAS in the upper range for the burst combinations with the 10,000-Hz carrier frequency. No subject found any burst rate accompanied by a 10,000-Hz carrier frequency to be an acceptable combination. Because of the amount of pain experienced by subjects receiving the 10,000-Hz carrier frequency, we believe the present use of this frequency in combination with bursts is questionable. Although the ratings on the VAS favor the burst combinations of the 2,500-Hz carrier frequency over the other combinations, no statistical significance was found between mean pain intensity ratings of burst combinations with either the 2,500-Hz or the 5,000-Hz carrier frequency. This statistical finding implies that the physical therapist can apply burst combinations with a carrier frequency of 2,500 or 5,000 Hz without patients perceiving any difference in pain intensity.

The milliamperage increased as expected for carrier frequencies of 2,500 and 5,000 Hz. This increase of peak current follows the concept of strength duration, in that current amplitude increases as the pulse or phase durations decrease. The results found for subject responses to the carrier frequency of 10,000 Hz disagree with the strength-duration concept because the milliamperage decreased from that required to produce torque of 50% of MVC. In general, the correlation coefficients indicated that little to no relation existed between the two variables (milliamperage and pain intensity ratings), which agrees with the findings of others.

Subjects more often chose burst combinations with the 2,500-Hz carrier frequency than with any other carrier frequency. The 2,500-Hz carrier frequency had the longest phase duration among the combinations studied. This finding appears to agree with that of Baker and coworkers, who reported that pulses of 300 microseconds' duration were perceived as more comfortable than those of 50 microseconds' duration. This observation is consistent when considering the amount of peak current delivered to obtain the equivalent of 50% of MVC with NMES in this study. The peak current recorded in our study was greater for the burst combinations with the 5,000-Hz carrier frequency than for either the 2,500-Hz or the 10,000-Hz carrier frequency when readings were taken of the mean milliamperage reported for these stimulus combinations. Stimulus characteristics that are comfortable at one level do not appear to guarantee comfort when applied at other levels of muscle contraction. Thus, the clinician may have to try different stimulus combinations on subjects at different current training levels.

Because of subject variation on VAS ratings in this study, we recommend that patients be given a choice of carrier frequencies prior to using the "Russian" current for muscle performance enhancement. For example, as the number of subjects selecting combinations of burst frequencies (50, 70, and 90 bps) with 2,500 Hz and 90 bps with 5,000 Hz were most commonly associated with the least pain, the patient could be given a brief stimulus (10 seconds) of each. From this stimuli exposure, the patient would be able to select the combination of choice for treatment or training purposes. Delayed onset of muscle soreness emerged as the study progressed, but because subjects rated their pain immediately following each stimulation sequence, no VAS ratings covered this situation.

**Conclusion**

No statistically significant difference was found between combinations of

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**Table 3. Number of Subjects Selecting Combinations of Burst and Carrier Frequencies as Most Comfortable (N=27)**

<table>
<thead>
<tr>
<th>Burst Frequency (bps)$^a$</th>
<th>Carrier Frequency (Hz)</th>
<th>2,500</th>
<th>5,000</th>
<th>10,000</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>4</td>
<td>2</td>
<td>0</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>70</td>
<td>5</td>
<td>3</td>
<td>0</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>90</td>
<td>9</td>
<td>4</td>
<td>0</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>18</td>
<td>9</td>
<td>0</td>
<td>27</td>
<td></td>
</tr>
</tbody>
</table>

$^a$Bursts per second.
burst frequencies (50, 70, and 90 bps) and carrier frequencies of 2,500 and 5,000 Hz. All burst combinations with carrier frequencies of 2,500 and 5,000 Hz differed significantly from burst combinations with the carrier frequency of 10,000 Hz. Data thus permit the conclusion that subjects be given trials of selected combinations of burst and carrier frequencies to choose the least painful stimulus combination.

References

1 Babkin D, Timtsenko N, trans. Notes from Dr YM Kots's (USSR) lectures and laboratory periods, Canadian-Soviet exchange symposium on electrostimulation of skeletal muscles; Concordia University, Montreal, Quebec, Canada; December 6–15, 1977.


