Effect of Auditory Rhythm on Muscle Activity

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The changes in the electromyogram patterns of two antagonist muscles were studied when female subjects performed a motor task with and without an auditory rhythm. During the performance of the motor task without the rhythm, the subjects demonstrated a common and consistent personal tempo and a common electromyogram pattern. With the imposed timing of an even or uneven rhythm, the initiation and duration of the electromyograms changed significantly for subjects in both rhythm groups. Variations of electromyograms decreased significantly for subjects in the even-rhythm group and increased significantly for subjects in the uneven-rhythm group. The authors suggest specific ways in which rhythm can be used in rehabilitative techniques to modify the onset, duration, and inconsistency of muscular activity.

Key Words: Motor activity, Auditory perception.

Basic biological functions demonstrate established repetitive tempos. Music produces various changes in blood pressure, galvanic skin resistance, and respiratory rates, and thus can affect the tempo of biological functions. In the therapeutic setting, music and rhythm have traditionally been used as adjuncts to promote generally increased muscle activity and motor coordination. This study focused on the role of rhythm as a key to the integrative process underlying motor performance; namely, could man’s own internal organization of movement be facilitated by exposure to specific external rhythms? The purpose of this study was to answer two questions:

1. In the performance of a coordinated movement, would an external rhythm affect the pattern of electrical activity of opposing muscles?
2. If changes in the pattern did occur, were they results of a unique neurological response, or merely artifacts of a different tempo of performance?

If a motor task performed to a rhythm were a distinctive response, rhythm could be used in the treatment of patients as a technical means to produce specific patterns of muscle activity.

Several studies have examined the effects of sound on muscular activity. Bickford discovered increased and latent EMG activity in neck, arm, and leg muscles in response to auditory clicks. These responses could not be attributed to body position or to the startle response. In 1957, Sears looked at the effects of music on EMG activity in flexor and extensor muscles of the right forearm. He concluded that generally increased EMG activity correlated strongly with stimulating music, while decreased EMG activity correlated less strongly with sedative music. Mayer and colleagues examined changes in the EMG pattern of muscles when an upper extremity motor task was performed at different speeds. Slower movements demonstrated continuous EMG patterns, while faster movements demonstrated multiphasic burst patterns.

Other studies investigated persons’ internal timing of movements. Rimoldi examined the speeds of performing many activities of daily life from physical acts, such as swinging an arm or bending the body, to verbal and perceptual reaction times. Results showed that each individual performing an act followed a specific and consistent speed, which that individual repeated over time. However, different individuals performed the same activity at various speeds. Smoll and Schulz looked at the repetition of the specific motor task of swinging one arm (standardized by

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mechanical equipment) at a self-paced tempo. They also found that each individual demonstrated a preferred and repetitious personal tempo and that this tempo varied from one individual to another.

Jones and Watt studied personal tempo as related to EMG activity and discovered that all subjects chose a consistent and accurate personal speed of repetitive hopping. Unlike the results of Rimoldi, and Smoll and Schulz, this preferred frequency was the same for all subjects. Moreover, all subjects demonstrated a consistent EMG activity pattern in the gastrocnemius muscle: EMG activity began before contact of the foot with the ground—before any physiological stretch reflex could occur. At the time the foot touched the ground, a monosynaptic stretch reflex was elicited. A latency period of little or no activity then occurred, followed by a polysynaptic burst of activity. This final, sustained burst of EMG activity started before the fastest voluntary response time. Because of this, Jones and Watt called it a functional stretch reflex.

Jones and Watt then observed the changes in EMG activity when subjects hopped at a faster and at a slower speed than the preferred frequency. In both cases, EMG activity continued to start before the foot touched the ground but increased or decreased in number of milliseconds before foot contact. Jones and Watt theorized that, in the faster tempo, too little time elapsed for the functional stretch reflex to be initiated; during the slower tempo, the functional stretch reflex was completed before it could be used to produce the upward push of the hopping leg. They inferred, then, that the sustained burst of polysynaptic EMG activity at the faster and slower tempos was no longer a functional stretch reflex but a voluntary response.

Previous studies, therefore, have shown that faster and slower speeds of performance change the timing and pattern of muscle activity, but have not discussed the effect of rhythm on muscle activity. Because of this lack of information, our study was designed to investigate the changes in the timing and pattern of EMG with and without rhythm.

**METHOD**

First, we established a base-line by designing a repetitive upper extremity motor task in which the primary motion occurred at the elbow joint. We expected all subjects who performed the motor task at their own pace to demonstrate a consistent and shared frequency with a corresponding timing and pattern of EMG in the biceps brachii and medial head of the triceps brachii (medial triceps) muscles. This base-line was called the personal tempo of performance.

In the next step, the subjects performed the same motor task synchronized with an auditory rhythm. We expected changes to occur in the timing and pattern of EMG, but without clues from the literature, we could not predict the direction of change. However, we looked for changes in the same factors studied by Mayer and associates and Jones and Watt: the initiation and duration of EMG activity of each muscle. Additionally, we decided to examine two other factors: 1) we expected the pattern of interaction of the two antagonist muscles (biceps brachii and triceps brachii) to change and 2) we expected the variation of EMG duration—as a measure of muscle activity organization—to decrease with the addition of rhythm because we believed rhythm could aid in organizing muscle activity.

Finally, we used two different rhythms—even and uneven. We expected each rhythm to produce unique changes in the initiation, duration, and variation of EMG activity and in the interaction of the two muscles. Unique changes would suggest a specialized, rather than a general, effect of rhythm, and would support a neurological explanation rather than a general behavioral response.

**Motor Task**

The motor task was designed as a specific sequence of hitting three targets while using flexion and exten-
sion of the elbow. Subjects hit the targets in the following pattern: Target 1, one time; Target 2, three times; Target 3, two times.

Subjects were carefully taught the correct kinematics for hitting the targets. Each subject was instructed to hold a metal peg in her left hand, ulnar side parallel to the target board (Fig. 1). The wrist remained in a neutral position. The subject was instructed to raise and lower her hand vertically by flexing and extending the elbow only. When a subject hit the target, the elbow was extended in a position of 0 to 10 degrees flexion. When a subject lifted the peg from the target, she flexed her elbow between 90 and 145 degrees.

Subjects

All 24 women who participated in the study were between the ages of 18 and 35. They had no physical or hearing disabilities and were all right-arm dominant. The subjects were members of a university community and were randomly assigned to one of three groups of eight persons each: control group, even-rhythm group, and uneven-rhythm group.

Target Board

The target board was constructed of three metal targets (40.63 mm × 69.27 mm) secured to the top of a rectangular wooden board. The targets were placed on the lower left, upper center, and lower right areas of the board and were labeled Target 1, Target 2, and Target 3, respectively (Fig. 2). The board was placed on a table in front of the sitting subject. When the subject contacted the target with the metal peg in her hand, an electrical circuit was completed and the contact recorded.

Electrodes

The subjects performed the motor task after two Beckman miniature surface electrodes were placed 1 mm apart on the skin covering the biceps brachii muscle belly and the medial head of triceps brachii muscle belly of the left, or nondominant, arm. Skin resistance for placement of the electrodes was reduced below 5,000 Ω. An eight channel Grass EEG* with inkwriting recorder and paper speed of 1 mm/30 msec was used to record EMG activity. Measurements from the three pieces of equipment (target board, taped rhythm, and EMG machine) appeared on the readout (Fig. 3).

Rhythm

The pattern for the uneven rhythm was chosen from the “Seashore Test for Musical Ability” and can be visually stated as 1 - 2 - 3 - 4 - 5 - 6. An equal measure of time was used for the even rhythm and can be stated as 1 - 2 - 3 - 4 - 5 - 6. Both rhythms were in 6/8 time. The frequency of the recorded beats was between 150 and 450 cps and the decibel level of each beat was 25.14, with a standard deviation of 7.89.

Procedure

The subjects performed the motor task during two sessions. During the personal tempo session (day 1), all subjects performed the motor task at their own paces. During the second session (day 2), the subjects in the control group again executed the motor task at their own paces. The subjects in the even-rhythm group learned to execute the motor task in rhythm with the even beat; the subjects in the uneven-rhythm group...
group learned to perform the motor task in rhythm with the uneven beat. The investigators determined that the task had been learned when the signals of the tape-recorded beats and the signals from the targets were synchronized. The criterion for synchronization was an overlap of the two signals with a ± 3.12-mm (1/8-in) margin. Once the motor task was learned, the subject performed four consecutive repetitions. The EMG activity of both muscles, the target signals, and the taped rhythm were recorded (Fig. 3).

Measurement and Analysis

The raw EMG data from the four repetitions of the motor task were visually examined. One section of a single motor task (a total of six target contacts beginning with Target 1) was selected for analysis because it contained the most clearly identifiable interference patterns.

Initially, the single motor task was qualitatively assessed. Each interference pattern of biceps muscle activity was lined up with the electrical signal of its respective target contact. We then observed when the onset of the individual interference pattern occurred in relation to the time of target contact. Each interference pattern of medial triceps EMG activity was similarly lined up and scrutinized. Finally, we compared the pattern of the two antagonist muscle groups.

After the qualitative assessment, quantitative measurements were made on biceps EMG activity. The medial triceps EMG activity was not as clearly defined as the biceps and, therefore, was more difficult to assess quantitatively. As a result, we decided to measure duration and variation of biceps brachii EMG activity.

The duration of a single interference pattern was determined by measuring the horizontal distance from the first action potential spike of the interference pattern to the last spike before the silent period that followed (Fig. 4). Each interference pattern corresponding to the six target contacts of the selected motor task was individually measured. Neither amplitude nor vertical height of EMG recording was measured or analyzed.

Variation of muscle activity was defined as the standard deviation in the duration of EMG activity. One standard deviation was mathematically computed from the duration of the six interference patterns. A single datum of the standard duration was recorded for each subject for each session.

The following statistical procedures were used to analyze the quantitative data. In order to determine if inherent differences existed between subjects, the Student's t test was used to compare the duration of EMG used by each group during Session 1. Then a t test of matched observations was used to compare the duration of EMG from Session 1 to Session 2. Specifically, the duration recorded for Target 1, Subject 1, Session 1 was compared with the duration for Target 1, Subject 1, Session 2. This was done for all six targets for all eight subjects in each group (n = 48 as 6 targets × 8 subjects of one group during Session 1 were compared with the same 6 targets × the same 8 subjects during Session 2). In this manner, each subject served as her own control. The statistical results would then reflect change in the duration per target for each subject rather than a change in mean duration of six targets for an average subject.

To analyze the variation of EMG activity, nonparametric tests were used because we could not assume the standard deviation values would be normally distributed. The rank sum test was used to compare the standard deviation of each group during Session 1 to validate again that, initially, no significant differences existed between the groups. Then a Wilcoxon sign-rank test was used to compare the change in standard deviation from Session 1 to Session 2. Here again, matched observations were used. The standard deviation for Subject 1 during Session 1 was com-

Fig. 4. Measurement of movement time from a recording of an EMG interference pattern.
RESULTS

During Session 1, all subjects demonstrated the same preferred frequency of 2.08 targets hit per second. (No significant difference occurred among the control and even- and uneven-rhythm groups for Session 1.) The control group performed the motor task at this same frequency during Session 2.

During Session 1, one major type of EMG pattern appeared common to most subjects of all three groups and this pattern was also continued by the control subjects in Session 2. The biceps brachii pattern of muscle activity occurred reciprocally to the triceps brachii muscle activity (Fig. 5A). Just before target contact, while the elbow was being extended, a small burst of medial triceps muscle activity occurred without evidence of any biceps muscle activity. The medial triceps muscle activity continued throughout the period of target contact. Medial triceps EMG activity ended and biceps activity began approximately 33 msec after target contact was completed. Biceps EMG activity then became silent as medial triceps activity again resumed just before the subsequent target contact. In some cases, a short overlap of simultaneous biceps and medial triceps EMG activity occurred.

When an auditory rhythm was imposed during the second session, the EMG pattern used by both experimental groups showed cocontraction of medial triceps and biceps muscle activity. In a few subjects, medial triceps muscle activity occurred continuously throughout the motor task. Biceps muscle activity began before target contact rather than after a latency period as in Session 1 (Fig. 5B).

Quantitatively, the duration of biceps EMG activity increased significantly from Session 1 to Session 2 for both experimental groups. As stated previously, duration of biceps EMG activity for each target was used in the statistical analysis. However, the Table illustrates the change by giving values for individual subjects as well as group means. The average duration per target for the even-rhythm group was 13.33 msec during Session 1. This increased significantly to 19.67 msec during Session 2 ($t = -6.35, \text{df} = 47, p < .01$). The average duration per target for the uneven-rhythm group was 15.98 msec during Session 1. This also increased significantly to 23.38 msec during Session 2 ($t = -4.96, \text{df} = 47, p < .01$).

The variation of EMG activity showed opposite results for the two experimental groups. During Session 1, no significant differences in variation occurred for any of the three groups of subjects. The control group did not vary from Session 1 to Session 2. However, the variation for the uneven-rhythm groups did increase significantly from Session 1 to Session 2 ($T = 35, \text{df} = 8, p = < .02$). The average standard deviation was 7.9 msec during Session 1 and 10.94 msec during Session 2 (Table). Figure 6 shows that the variation for the even-rhythm group decreased significantly from Session 1 to Session 2 ($T = 4, \text{df} = 8, p = < .03$). The average standard deviation for the even-rhythm group was 7.46 msec during Session 1 and 4.63 msec during Session 2.

DISCUSSION

The results of this study demonstrated that the subjects used a preferred frequency of movement in the performance of a motor task. This preferred frequency of 2.08 targets hit per second closely corre-
control the indirect effect of the imposed timing. The motor rhythms appear to be the result of reciprocal agonist-antagonist muscle activity pattern. During Session 2, the subjects' EMG patterns showed reciprocal timing with very little overlap. Studies in the acquisition of motor skills have revealed EMG patterns of trained individuals in which even-rhythm X resembled the EMG pattern of a trained athlete or of a subject trained in a motor task. This is assumed to be the most efficient EMG pattern with the least variation. Yet the performance of the same motor task that was skillfully performed at a personal tempo in Session 1 became a new motor task to be learned to a rhythm in Session 2.

Another change in the EMG pattern, however, must be explained. In Session 1, biceps muscle activity began after target contact, but biceps muscle activity in Session 2 began much before target contact. This change is similar to the change in EMG seen by Jones and Watt when their subjects hopped at faster and slower speeds. Their subjects demonstrated a functional stretch reflex in the gastrocnemius muscle when hopping at their preferred frequencies. When hopping at slower or faster speeds, the onset of EMG changed so that Jones and Watt no longer characterized the EMG as a functional stretch reflex but rather as a volitional response. During Session 1 of our study, the biceps muscle activity began just after target contact, when the elbow was still extended in order to contact the target. The initiation of biceps activity thus occurred simultaneously with a mechanical stretch of the biceps. No biceps activity was seen before, or at the time of, target contact, which indicates the subjects used little or no biceps contraction to decelerate the extension of the elbow. In Session 2, however, biceps muscle activity began before target contact. The initiation of biceps muscle activity could no longer be attributed to any physiological stretch of the biceps, because the elbow was already in a flexed position. A possible explanation for this early initiation of biceps activity during Session 2 is that the biceps muscle was aiding the subject to decelerate the forearm in order to contact the target with the exact beat of the rhythm. As in the Jones and Watt study, the onset of muscle activity may have changed from a stretch reflex during Session 1 to a volitional response during Session 2, indicating that rhythm may serve to alter the role of muscle activity.

While both even and uneven rhythms produced a similar change in initiation and duration of EMG activity, the two rhythms produced different changes in the variation of EMG activity used for each target hit. The uneven rhythm increased variation significantly, while the even rhythm decreased variation significantly. Analysis of the data indicated that the increased variation of the uneven-rhythm group appeared to be a direct result of the uneven timing of the beat. But no such mechanical reason can explain the greatly decreased variation for the even-rhythm group. One assumption made about a skilled motor performance is that it reflects the most efficient recruitment of motor units because these units are recruited more quickly and in greater synchronization than during unskilled performance. As we stated earlier, the EMG pattern of Session 1 resembled that of a subject trained in a motor task. This is assumed to be the most efficient EMG pattern with the least variation.

One major EMG pattern appeared common during the performance of the motor task at the preferred frequency. Not only was this EMG pattern consistent among individuals and over time, but it also closely resembled the EMG pattern of a trained athlete or of a subject trained in the performance of a motor skill. Studies in the acquisition of motor skills have revealed EMG patterns of trained individuals in which opposing muscles showed reciprocal timing with very little overlap. Conversely, untrained subjects learning a motor task demonstrated cocontraction with increased duration of muscle activity. During Session 1 of our study, the subjects demonstrated a reciprocal agonist-antagonist muscle activity pattern. During Session 2, the subjects' EMG patterns showed cocontraction of biceps and medial triceps muscle activity and a significant increase in duration of biceps muscle activity. Thus, the EMG changes that occurred with the rhythms appear to be the result of the indirect effect of the imposed timing. The motor activity and a significant increase in duration of bi-

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Fig. 6. Change in variation of EMG with and without rhythm. A. Session 1: Varied duration for each interference pattern. B. Session 2: Consistent duration for each interference pattern.

Task to an even rhythm demonstrated even greater decreased variation. Basmajian described the athlete's continued drill to perfect a skilled movement as a "progressively more successful repression of undesired contractions." It is possible that an even rhythm aids this repression of undesired contractions more than the normal recruitment pattern of a skilled motor task. Little information about the variation of EMG activity exists in the literature.

In our study, one even and one uneven rhythm of equal duration were compared to a control condition (the personal tempo). In future studies, investigators might examine changes in EMG when other modified rhythms are used. That is, investigators could explore rhythms significantly slower or faster than the personal tempo. Other studies might be designed so that the rhythm matched the personal tempo exactly. In this case, the sound of the rhythm would be the only added variable.

CONCLUSIONS

This study demonstrates that EMG changes do occur with the addition of an auditory rhythm and suggests possible neurological mechanisms to explain these changes. Increased EMG activity duration and cocontraction occurred as the motor tasks performed to these rhythms became new skills to learn. The initiation of muscle activity switched from after to before target contact. This could possibly be explained by a change in the role of muscle activity from reflexive to volitional. The variation of EMG activity decreased with an even rhythm, which may be explained by a more efficient recruitment order of motor units than that usually seen in skilled performance of motor tasks.

These changes in muscle activity could be applied to the treatment of patients in several ways. A therapist planning to encourage longer muscle activity for increased joint stability might impose a rhythm during performance of a motor task such as walking. This would make the task a new skill to be learned and would result in longer duration of muscle activity with increased cocontraction, that is, increased stability of muscles surrounding a joint. If a therapist wanted a muscle to become active sooner (eg, initiating ankle dorsiflexion during preswing phase of gait), the therapist could design a motor task in which the patient's foot contacted a target (using dorsiflexors as the decelerating muscles) at the patient's personal tempo. Then, by adding a slower and even beat, the muscle activity would be initiated sooner, in an effort to control the movement. Finally, if a therapist wanted to decrease the inconsistent activity of a muscle (eg, a hypertonic muscle), the therapist could design a repetitive task to an even beat. This would enhance decreased variation in muscle activity and produce more efficient recruitment of motor units. In this manner, the effects of external rhythm imposed on movement could be explored as a specific neurological technique to enhance neuromuscular coordination.
REFERENCES