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The Effects of Step Height, Cadence, and Choreography on Biochemical Factors in Step Aerobics

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THE EFFECTS OF STEP HEIGHT, CADENCE, AND CHOREOGRAPHY ON BIOMECHANICAL FACTORS IN STEP AEROBICS

by

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Stacie Moore

THE EFFECTS OF STEP HEIGHT, CADENCE, AND CHOREOGRAPHY ON BIOMECHANICAL FACTORS IN STEP AEROBICS

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The problem of the study was to determine the effect of step height, speed, and choreography on ground reaction forces, electromyography of the knee extensors, and center of gravity displacement in step aerobics. Two step heights, 6 and 8 in.; two speeds, 126 and 132 bpm; and three steps, basic step, turn step, and hop step, were studied for a single subject across 5 trials. The muscles studied included the rectus femoris, vastus lateralis, and vastus medialis. Results indicated: (a) significant difference existed between the cadences as well as between the step heights for the sagittal plane center of gravity; (b) the 6-in. step height produced greater vertical impact forces than the 8-in. step, but not significantly for each step; (c) the step heights were significantly different across steps for the area under the curve for the three muscles studied; and (d) for vastus medialis, significant interactions were found for the higher step height, faster cadence, and higher impact step which were not seen for the other two muscles studied. The conclusions were: (a) the 6-in. step height produced greater vertical impact forces than the 8-in. step height; (b) the body does not have time to move through its full range of motion at the faster cadence or the higher step heights; (c) a greater EMG response was produced by the vastus lateralis, rectus femoris, and vastus medialis for the 8-in. step than for the 6-in. step; and (d) in a fatigued state a participant is less consistent at the faster cadences, higher step heights, and higher impact steps.

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CHAPTER I

INTRODUCTION

Americans are becoming increasingly aware of the benefits that participating in regular aerobic exercise can have on their health. This is causing many previously sedentary people to begin looking for an exercise modality that is best suited for them. These people are looking for safe, low-impact activities that are not associated with a high risk of injury.

Many exercise participants choose step aerobics as their preferred form of aerobic activity. Step aerobics has nearly replaced high- and low-impact aerobic dance in most aerobics studios. High-impact aerobics was associated with a high incidence of injury, and many people began looking for a modality that would be as intense, but have a lower impact. Step aerobics began as a slower form of aerobics that was lower in impact and caused significantly fewer injuries than other forms of aerobic exercise such as running and high-impact aerobics (Richards et al., 1995). However, as instructors looked for new ways to increase the intensity of step aerobics, they turned to higher impact moves and a faster cadence. Research supports that these high-impact moves, often called propulsion steps, as well as the faster tempo, can in fact increase the intensity of the activity (Francis, Poliner, Buono, & Francis, 1992). This, however, is making step aerobics classes very much like the high-impact classes that they replaced.

Statement of the Problem

The problem of this study was to determine the effects step height, cadence, and choreography used in step aerobics had on ground reaction forces, electromyography (EMG) of the knee extensors, and center of gravity displacement in a fatigued state. Two step heights, 6 and 8 in.; two speeds, 126 and 132 bpm; and three steps, basic step, turn step, and hop step, for a single subject across five trials were studied.

Purpose of the Study

Step aerobics has become popular because participants are allowed to choose between various step heights. The most common step heights are 6 and 8 in., and participants usually choose a height that corresponds with their ability level. Some research has been done on the cardiovascular effects at different step heights, but very little research has been done on the effects that step heights might have biomechanically. Most of the research in this area has focused on the vertical ground reaction forces (VGRF) associated with the activity. Researchers have found that propulsion moves, faster cadence, higher step height, and fatigue cause an increase in vertical ground reaction forces. The researchers do not agree as to whether or not these increases lead to a greater incidence of injury. Some researchers concluded that the propulsion steps produced lower VGRFs than traditional high-impact aerobics (Dyson & Farrington, 1995; Johnson, Rupp, Berry, & Rupp, 1992). However, Dyson and Farrington (1995) found that these moves produced greater VGRFs than low-impact aerobics. None of the researchers examined any turning steps, which are very common in step aerobics. Turning steps introduce torques on the body that need to be examined. Other variables, such as center of gravity, body alignment, and muscle recruitment have not been examined at all to see how these variables are affected by higher step height, faster cadence, propulsion moves, and fatigue in step aerobics. In this study common step combinations in step aerobics at two different heights, as well as at two different speeds, were examined to determine the soundness of this new activity.

Delimitations

The following delimitations were identified for this study:

1. The subject was a female aerobics instructor.

2. The subject maintained the recommended cadences for step aerobics of 126 bpm and 132 bpm.

3. The subject performed at two step heights: 6 and 8 in.

4. The subject performed three basic steps: basic alternating step, a turn step, and a hop step.

5. The subject was in a fatigued state before being measured.

6. The equipment or technique used to measure the dependent variables were a force platform, electromyography, and cinematography.

7. Three knee extensors, vastus lateralis, vastus medialis, and rectus femoris, were studied.

8. The dependent variables were ground reaction forces, muscle recruitment, and center of gravity displacement.

9. The subject performed 5 trials for each condition.

Limitations

The limitations of the data were as follows:

1. One subject may not be representative of the general population which could affect the external validity.

2. The placement of the electrodes on the subjects was estimated as accurately as possible in relation to each anatomical landmark.

Assumptions

The following were assumptions for the study:

1. The subject performed all of the step combinations correctly.
2. The force platform simulated the Reebok step (Reebok, Inc.).
3. The equipment worked properly.
4. The subject was fatigued to the same extent for each testing condition.

Research Hypotheses

The following hypotheses will be tested in this study:

1. The EMG response will be greater at the 8-in. step height than at the 6-in. step height.

2. The ground reaction forces will be greater at the 8-in. step height than at the 6-in. step height.

3. Center of gravity displacement will be different in the 8-in. step than in the 6-in. step.

4. The EMG response will be greater at the 132 bpm than at the 126 bpm.

5. The ground reaction forces will be greater at the 132 bpm than at the 126 bpm.

6. Center of gravity displacement will be different at the 132 bpm than at the 126 bpm.

7. The EMG response will be greater for the hop step than for the basic step or the turn step.

8. The EMG response will be different for the basic step than for the turn step.

9. The ground reaction forces will be greater for the hop step than for the basic step or the turn step.

10. The ground reaction forces will be different for the basic step than for the turn step.

11. The positive and negative torques will be greater for the turn step than for the basic step or the hop step.

12. The positive and negative torques will be greater for the basic step than for the hop step.

13. Center of gravity displacement will be greater for the turn step than for the basic step or the hop step.

14. Center of gravity displacement will be greater for the basic step than for the hop step.

Definitions

The following terms were defined for the study:

1. Aerobic activity: A rhythmic and continuous activity that provides a sufficient cardiovascular overload to stimulate increases in stroke volume and cardiac output.

2. Basic step: This step involves the participant stepping up onto the step, first with one leg and then with the other, and then back down again. This motion occurs in the sagittal plane.

3. Electromyography: A noninvasive technique used to measure muscle activity.

4. Force platform: An instrument that can measure the force, direction, and time of an object that is in the contact phase.

5. Hop step: This step involves the participant beginning with his or her feet together facing the step, then jumping with both feet together to the top of the step, and then stepping down one foot at a time. This step's motion occurs in the sagittal plane.

6. Recruitment: The number of motor units required to produce a specific gradation of a muscle's force.

7. Step aerobics: A form of aerobic dance that incorporates a step of various heights usually ranging from 4 to 10 in.

8. Turn step: This step begins with the subject standing at one end of the board with his or her frontal plane perpendicular to the longitudinal axis of the step. Next with the leg nearest the step the subject steps onto the end of the step. After foot contact, the subject rotates the body by pivoting the contact foot 90°. At the end of the rotation, the opposite foot contacts the step at the opposite end of the step. Once the second foot makes contact, the body continuous to rotate, about 90°, in the same direction, pivoting about the contact foot. The subject then steps down with the

original foot followed by the other foot. The subject ends in the same position that he or she started but facing the opposite direction.

CHAPTER II

REVIEW OF RELATED LITERATURE

The literature related to the biomechanics of step aerobics is reported in this chapter. The following topics will be discussed: (a) background of step aerobics, (b) step aerobics and intensity, (c) ground reaction forces, (d) injury data, (e) single subject defense, and (f) summary.

Background of Step Aerobics

Step aerobics was first introduced in 1989 as a low-impact alternative to traditional aerobic dance. It involved a bench commonly referred to as a step which could be set at varying heights ranging from 4 to 12 in. The music was slower ranging from 118 to126 bpm, than the traditional high-impact aerobics with speeds up to 150 bpm. These factors presented exercise participants with an aerobic dance alternative that did not have as high an incidence of injury as traditional aerobics. Over the past 10 years, the evolution of step aerobics has been characterized by several choreography changes: (a) faster cadences, (b) higher step heights, and (c) higher impact. These changes were brought on by the demand for step aerobics to elicit an increased training intensity for individuals of greater fitness levels; however, nowadays it is being taught to advanced and beginning students alike.

Step Aerobics and Intensity

Step Height

A common way for step aerobics participants to increase their workout intensity is to raise the level of their step. The most popular step heights are 6 and 8 in.; however, step heights range from 4 to 12 in. Many researchers have studied the effect that step height has on energy expenditure. Most studies have found a significant difference in energy cost between step heights (Scharff-Olsen, Williford, Blessing, & Greathouse, 1991; Stanforth, Stanforth, & Velasquez, 1993). These researchers used females and measured their energy expenditure while performing step aerobics on benches ranging from 4 to 12 in. They found that as the bench height increased so did the participants' energy expenditure. Another study which involved both men and women found a significant linear trend between step height and energy cost (Francis et al., 1992).

With this information, many exercise participants have wondered when and how high they should raise their step heights. Most researchers agree that a step height should be based on the individual's level of fitness, movement coordination, and weight. Any knee or orthopedic problems should also be taken into consideration. It has been reported that the step height should never be so high that the knee flexes beyond 90° (Kravitz & Deivert, 1991). Kravitz and Deivert claimed that a step height that is too high may cause pressure on the lower back which could lead to injury. They feel that all students should begin with a 4- or 6-in. step and suggested that participants with knee problems choose another cardiovascular activity.

Cadence

Music speed is another variable that is often manipulated in step aerobics. Step Reebok guidelines suggested a speed of 118 to 122 bpm for all step aerobics classes. It has been reported that the music speed ranges from 118 to 126 bpm. However, this is considered slow by many aerobics instructors. A new cadence called super step is gaining in popularity where the music ranges from 128 to 132 bpm. Researchers have shown that a faster cadence can increase the percent VO_2 max by as much as 5% during an exercise session (Stanforth et al., 1993). This increase was found when comparing 120 bpm versus 128 bpm.

Most researchers, however, agree that increasing the cadence beyond 126 bpm would not be safe (Kravitz & Deivert, 1991). These researchers believed that music with faster tempos would not allow the muscles to go through their full range of motion which could lead to overuse injuries.

Choreography

Another variable that is often manipulated in step aerobics is the choreography. Many studies have been conducted to compare energy expenditures of different moves. The most demanding moves in terms of energy cost have been found to be the propulsion moves. Propulsion moves are high-impact moves, meaning that at times neither foot is in contact with the floor or step. These moves include such things as lunge steps, hops, or run steps. These steps are very popular with aerobic instructors because they elicit a higher heart rate than the basic moves. In one study it was reported that when the subjects performed plyometric lunging their VO_2 percent went up significantly when compared with the basic step (Scharff-Olsen et al., 1991).

Another study involved 15 males and 15 females performing a step routine that contained propulsion steps. These researchers found that the typical routine elicited 57.9 $\pm$ 8.9% of VO_2 max, whereas the propulsion steps elicited 79.0 $\pm$ 8.6% of VO_2 max (Francis et al., 1992).

Ground Reaction Forces

Step Height, Cadence, and Choreography

Many researchers have investigated the effects step height, cadence, and choreography have on ground reaction forces created during step aerobics. Most of the researchers focused on the vertical impact forces, specifically peak vertical ground reaction forces and time to peak vertical impact force. Most of these studies were designed to measure the ground reaction forces elicited as the subject stepped down onto the force platform from the bench.

Many researchers have examined the effect of step height on ground reaction forces (Johnson, Johnston, & Winnier, 1993; Moses, Blessing, & Wang, as cited in Scharff-Olsen, Williford, Blessing, & Brown, 1996). Johnson et al. (1993) compared the peak vertical ground reaction forces (PVGFs), peak vertical loading rates (PVLRs), and peak vertical impulses (PVIs) produced when performing step aerobics on a 6-, 8-, and 10-in. steps. These researchers concluded that the 6-in. step produced smaller PVGFs, PVIs, and PVLRs compared to the higher bench heights and would likely decrease the chance for foot and shank injuries when compared to stepping from higher step heights (Johnson et al., 1993).

Another investigation revealed that the vertical ground reaction forces associated with step heights of 6-, 8-, 10-, and 12-in. steps were different when the step height difference varied by as much as 4-in. (Moses et al., as cited in Scharff-Olsen et al., 1996). These researchers also looked at the effect stepping speeds and step patterns had on vertical ground reaction forces. The two speeds observed were 30 and 32 cycles/min. The three step maneuvers were basic, knee raise travel, and plyometric lunging. They found that the basic and the knee raise travel had much greater vertical ground reaction forces at 32 versus 30 cycles/min; however, there was no difference in vertical ground reaction forces (VGRFs) for the plyometric lunging at the two speeds. The plyometric lunging yielded higher peak VGRFs than either the basic or the knee raise travel under similar conditions. These researchers concluded that stepping rate, step height, and stepping pattern can vary VGRFs significantly in step aerobics.

Fatigue

In the past 5 years researchers have studied the effect of fatigue on the ground reaction forces produced during step aerobics. Step aerobics involves such complicated moves that researchers began to wonder if the body was still strong enough at the end of the workout to control such movements.

Spencer and Bartlett (1993) studied 10 experienced female step aerobics participants. These investigators studied both the basic and the lunge step. They tested the maximum vertical impact force as well as the maximum loading rates for these two step patterns at the beginning of the exercise session as well as the end. They found that there was a significant increase in the maximum loading rates and maximum vertical impact for both the basic and lunge from a fresh to fatigued state. These researchers suggested that this increase in the magnitude of impact and the rate at which load is applied in a fatigued state could lead to a predisposition for injury.

Another study involving 17 aerobics instructors performing a standard step routine on an 8-in. step came to a different conclusion (Johnson et al., 1992). Measurements for this study took place at 5, 20, and 35 min into the workout. Mean peak vertical ground reaction forces (PVGRFs) and time to peak forces (TTPFs) were measured when the participants stepped down from the step. This study found that mean PVGRFs were not different for the different times of the workout. Mean TTPFs for 5 min and 35 min differed, as did the mean TTPFs from initial contact to PVGRFs during push-off between 5 and 20 min, and 5 and 35 min. They concluded that the effect of fatigue on ground reaction forces was unclear because PVGRFs did not increase, but TTPFs did.

Dyson and Farrington (1995) examined ground reaction forces for four common step aerobics movements to determine how they were affected by fatigue during an hour-long session. The steps used for this study were the basic, v-step, knee-up, and repeaters. Measurements were taken as the subject stepped down off of the bench onto a force platform. The results indicated that the mean peak vertical forces at 5, 20, and 40 min were not significantly different; however, they did increase as exercise duration increased. The researchers also found that at the 5% level the basic step mean peak vertical force was significantly greater at 40 min than at the 5-min measurement. They concluded that with this particular step the greater forces may have been related to fatigue.

<u>Ground Reaction Forces of Other Activities</u>

A few researchers have compared the vertical ground reaction forces experienced in step aerobics with the vertical ground reaction forces experienced in other aerobic activities to determine which modalities are safer. Many injuries are believed to be related to the amount of VGRFs associated with the activity (Francis, Francis, & Welshons-Smith, 1985).

In one study, researchers compared the VGRFs associated with step aerobics, walking, slow jogging, low-impact marching, and high-impact double knee lifts (Johnson et al., 1992). They found that slow jog and high-impact moves created higher peak vertical ground reaction forces than step aerobics and were therefore considered not as safe a mode when injury potential was a factor. Low-impact marching results were inconclusive, and walking appeared to be the safest of all of the modes studied.

Dyson and Farrington (1995) compared step aerobic moves to both high and low-impact aerobic moves. They were interested in determining if step aerobics was truly a low-impact exercise as it had been advertised. The results indicated that high-impact moves had an overall mean peak vertical force ratio of 2.40 relative to body weight whereas low-impact moves had a significantly lower mean peak vertical force ratio of 1.30 relative to body weight. Step aerobics moves produced a mean peak vertical force ratio of 1.90 relative to body weight. The researchers claimed that this meant that step aerobics could more accurately be called a medium-impact activity since it is higher than low-impact yet lower than high-impact.

Injury

The research pertaining to step aerobics and its incidence of injury appears to be varied. Many researchers claimed that they did their research because of the high incidence of injury among step aerobics instructors (Johnson et al., 1993; Spencer & Bartlett, 1993). However, what little research has been done on the incidence of injury in step aerobics claims that it is safer than other common modalities. A group of researchers looked at this problem in a study in which they compared bench stepping aerobics to running to determine the incidence of injury for each. Fifteen women participated in running and 23 women participated in bench aerobics for 10 weeks. They exercised the same number of days a week for the same amount of time. They were to record daily any injuries that had occurred and how severe it was and where it was located. The severity scale ranged from Grade I, which was discomfort but did not alter daily activities, Grade II altered or ceased exercise, Grade III changed/altered daily activity and exercise, Grade IV sought professional medical care. Grade I injuries were the most commonly complained of injuries. The step aerobics group had more Grade I injuries than the running group. The running group had more Grade II and Grade IV injuries than step aerobics. Most of the Grade I complaints were believed to be just delayed onset of muscle soreness and therefore not true injuries, indicating that running produced more severe injuries than step aerobics.

Garrick, Gillen, and Whiteside (1986) have examined the incidence of injury in step aerobics and come to the same conclusion, that Grade I injuries made up the majority of complaints. They analyzed how many injuries per 100 hours of exercise were likely to occur. When including Grade I injuries, they reported that 6.09 injuries were associated with 100 hours of step aerobics. When Grades II, III, and IV injuries were used and Grade I eliminated, they found that only 0.29 injuries were associated with 100 hours of step aerobics. This indicates that step aerobics was not associated with a high number of debilitating injuries, but delayed onset of muscle soreness could plague many participants.

Single Subject Defense

Most research that is done in the area of exercise science involves studies of groups of people as opposed to single subjects. The idea is that a larger number of subjects may allow for a more accurate account of the general population. Some people argue that if you use a large number of people then you may lose some of the interindividual variability (Bates, 1996). Individual differences may be masked when examined in a group because the data are often averaged, which could eliminate certain individual characteristics. Another consideration is that it is not just the sample size that affects generalizability, but the number of trials or replications (Bass, 1987). A single subject design usually contains many trials for each condition. The more times a certain response is repeated with a single subject, the more likely it will happen with the general population.

Another reason to consider using a single subject as opposed to a group design would be to examine many aspects of one subject. It may be impossible to examine a lot of things about many subjects, whereas with one subject the researcher can perform many trials and have a lot of experimental conditions. This would allow for a very in-depth look at the condition the researcher was studying.

Summary of Related Literature

The literature suggested that an effective way to increase the energy cost of step aerobics is to increase the step height, cadence, and impact of the moves. Each study that involves increasing these variables tends to find that energy cost increases as well. However, most experts believed that increasing these variables may not be safe for the general population. They believed that a higher step height might put more pressure on the knee and back, and that a faster cadence does not allow the body to go through its full range of motion which could lead to overuse injuries. The concern with the choreography is that high-impact propulsion moves are being used, which are similar to the moves that caused so many high-impact aerobic dance injuries.

To determine if step aerobics was a safe alternative to other modes of exercise, many researchers examined the ground reaction forces associated with this activity. The results were somewhat varied for this section. Most of the researchers believed that step aerobics was safer than other modes such as high-impact dance and running; however, when compared to low-impact dance and walking, step aerobics was not as safe. Most researchers, however, measured the forces as the participant stepped down off of the step. They also tended to stick with the forward and traveling steps; no one analyzed any of the turning steps which are quite popular steps in step aerobics.

Researchers also examined the vertical ground reaction forces associated with higher step heights. Most researchers agreed that the VGRFs increase with step height, but it had to be a difference of about 4 in. to be significant. When examining the effect that speed and choreography had on VGRFs, researchers found that increased speed increased VGRFs as did higher impact moves.

A lot of researchers have examined the effect that fatigue has on VGRFs and have come to some varying conclusions. Most found that as the subjects became more fatigued their VGRFs increased; however, one study that involved aerobics instructors did not find this to be the case and concluded that their results were unclear as to whether fatigue increases VGRFs.

Most of the injury research indicates that step aerobics does not cause debilitating injuries, but rather minor muscle soreness. Aerobic participants do experience injuries, but most of them are believed to be related to delayed onset of muscle soreness. However, many experts believed that if you have orthopedic problems step aerobics may not be a good choice for cardiovascular activity.

More research needs to be done using varied steps to determine the safety of step aerobics. Most of the research dealt with the same step patterns and a few studies examined propulsion steps; no studies examined turn steps. Research also needs to be done in the area of electromyography of the muscles involved in step aerobics. Many of the researchers believed that in a fatigued state the muscles were no longer strong enough to control the movements. They came to this conclusion by examining the VGRFs, but examining the muscles themselves would give a better indication as to whether or not this was true. Finally, range of motion has not been directly studied to determine if it is true that at faster speeds the participants will be unable to move through their full range of motion. Once these questions have been addressed, professionals will have a better idea about the safety of step aerobics as a cardiovascular activity.

CHAPTER III

METHODOLOGY

The problem of the study was to determine the effects of step height, cadence, and choreography on ground reaction forces, EMG of the knee extensors, and center of gravity displacement in step aerobics for a single subject in a fatigued state. The investigator used a force platform to record the subject's ground reaction forces at each step height. Center of gravity and muscle recruitment were analyzed using cinematography and surface EMG, respectively. The following topics are covered in this chapter: (a) subject information, (b) research design, (c) instrumentation, (d) testing procedures, and (e) treatment of data.

Subject Information

The subject for the study was a 24-year-old female volunteer who attended Western Michigan University. The subject signed a consent form (see Appendix A). Approval to conduct this study was given by Western Michigan University's Human Subjects Institutional Review Board (see Appendix B). The subject was an aerobics instructor with at least 1 year of experience in step aerobics, who was teaching aerobics at the time of the study and was comfortable with the two step heights.

Research Design

The subject was involved in 12 experimental conditions that included three step combinations performed at two different step heights, with two different cadences. The three step combinations were a basic alternating step, a turn step, and a hop step. Each step combination was performed three times. All conditions were performed in a fatigued state. The research design was repeated measures. The subject performed 5 trials for each condition. The dependent variables analyzed were: (a) ground reaction forces, (b) muscle recruitment, and (c) center of gravity. Each dependent variable is defined below:

1. Maximum braking force is the greatest force acting in a horizontal forward position at foot contact.

2. Horizontal impulse during braking is the product of the force times time.

3. Maximum medial and lateral forces are the greatest forces acting left and right from their respective sides of the foot.

4. Vertical impact force is the force in a downward direction.

5. Time of vertical impact is the time it takes to reach maximum vertical force.

6. Vertical loading rate is the speed at which downward forces were created.

7. Maximum positive and negative torque is the maximum amount of rotational forces or torsion during contact.

8. Time to maximum positive and negative torque is the time from contact until maximum rotational force is achieved.

9. Peak EMG response is the maximum microvolts (μv) created by each of the muscles from the time of foot plant to the end of braking for each muscle.

10. Time to peak EMG is the elapsed time from foot plant to peak EMG for each muscle.

11. Area under the curve for the three muscles is the product of microvolts times time from the time of foot plant until the time of the end of braking for each muscle.

12. The center of gravity was observed with respect to the base of support. The Peak 5 version 5.2 computer software program was able to determine the center of gravity by analyzing the 20 anatomical points of the body that were digitized. Anterior/posterior and lateral motion were measured.

Instrumentation

The instruments used in this investigation are listed below:

1. Two Kistler type 9281B (Kistler Instrument Corporation, Amherst, NY) force platforms were used to measure the ground reaction forces.

2. Bipolar surface electrodes, Medi trace, 1 cm, silver-silver chloride (ECE 1801 Graphic controls, Buffalo, NY) were placed on the subject. The EMG electrodes were linked to Myosystem 2000 software program (Noraxan, Phoenix, AZ). This was used in conjunction with the Peak Motion Analysis hardware-software program (Peak Performance Technologies, Inc., Englewood, CO).

3. Two video cameras were used, a Panasonic HG4500 and a Panasonic WV-D5100HS (Panasonic Broadcast & Television Systems Company, Secaucus, NJ), set at a frequency of 60 Hz. Fugi Super VHS videotape was used.

4. A Panasonic AG 7350 video cassette recorder, a Sony monitor, and a Tenex 486 IBM compatible computer were used to digitize the film.

5. Peak 5 version 5.2 was the computer software program used to digitize the video and analyze the data.

Testing Procedures

Data collection took place in the Exercise Physiology and Biomechanics lab at Western Michigan University. Prior to the study, the subject signed a consent form. The consent form listed the testing procedures, possible risks, and electrode placement procedures.

The subject warmed up for 45 min before the testing session by teaching an aerobics class immediately prior to the testing. The subject performed the following combinations of conditions in a random order: (a) basic step, turn step, and hop step at the 6-in. step height with a cadence of 126 bpm; (b) basic step, turn step, and hop step at the 6-in. step height with a cadence of 132 bpm; (c) basic step, turn step, and hop step at the 8-in. step height with a cadence of 126 bpm; and (d) basic step, turn step, and hop step at the 8-in. step height with a cadence of 132 bpm.

Analog Data Procedures

Bipolar surface electrodes were placed on the subject's rectus femoris, vastus lateralis, and vastus medialis. The electrode detection surfaces were placed on the longitudinal axis of the belly of the muscle, 1 cm apart, and parallel with the muscle fibers. The placement sites were shaved and prepped prior to electrode placement.

The EMG electrodes were connected to a Myosystem 2000 EMG unit that was interfaced with the Peak Motion Analysis analog-to-digital module. This system provided raw EMG signals that were matched to the video.

The raw EMG signals were filtered using a root mean square procedure. The video-matched EMG data were analyzed by the Myosoft EMG software.

Two force platforms were supported by concrete to simulate a Reebok step. One was raised to a height of 6 in., and the other was raised to 8 in. The signal from the force platform was relayed to the computer and analyzed using the Peak 5 version 5.2 software package.

Two cameras were set on tripods 45 m from the subject, one perpendicular to the sagittal plane and one perpendicular to the frontal plane. The cameras were set at a height of 1 m level to the ground. A scaling factor of 1 m was used to offer a point of linear measure for digitizing. For each condition the subject performed each step three consecutive times. During the second step, analog and video data were collected. The steps and combinations were presented in a random order.

The video data were synchronized with the EMG and the force platform data through a 16-channel event synchronization unit (ESU, Peak Technologies, Inc.). A light-emitting diode (LED) was recorded on the videotape when a hand-held trigger was pressed. This matched the film to the EMG and force platform data for that period of time. The EMG and the force platform were set to begin recording 1.0 s prior to the LED signal and to end recording 3.0 s after the signal.

Digitizing Procedures

After the filming process was completed, the videotape was digitized. The following anatomical points were digitized: (a) extremity of the foot, (b) medial malleolus of the ankle, (c) center of the knee, (d) greater trochanter of the hip, (e) crotch, (f) sternum, (g) extremity of the hand, (h) center of wrist, (i) center of elbow, (j) corocoid process of the shoulder, (k) tragus of ear, and (l) top of head. The points of the legs and arms were digitized on both the right and left sides of the subject.

Manual digitizing was performed using the Peak 5 version 5.2 software program. The second step was analyzed for each step height and step combination.

Music

The subject kept the appropriate cadence by stepping in time with the music. The music chosen had a cadence of 126 bpm or 132 bpm. The music was started before any of the trials were recorded so the subject would have a chance to get in cadence with the music.

Treatment of Data

A completely randomized block design was used to analyze the results. The variables analyzed were the step heights, cadences, and step combinations. The step heights were 6 and 8 in., the cadences were 126 bpm and 132 bpm, and the steps included the basic, hop, and turn steps. ANOVAs were run to determine if there were significant differences among the three main effects. If significant effects were found among three or more means then the Tukey HSD test was run to determine where significance differences existed. Simple main effects and simple, simple main effects tests were used to examine significant interaction effects. This research used the .05 level of significance.

CHAPTER IV

RESULTS AND DISCUSSION

Introduction

The problem of this study was to determine the effect of step height, cadence, and choreography on ground reaction forces, EMG of the knee extensors, and center of gravity displacement in step aerobics for a single subject. The investigators used a force platform to record the subject's ground reaction forces at each step height. Center of gravity and muscle recruitment were analyzed using cinematography and surface EMG, respectively. In this chapter the results are presented in the following order: (a) force platform, (b) center of gravity, and (c) EMG. The discussion follows the results.

Results

Force Platform Data

Maximum Braking Force Data

Maximum braking force is the greatest forces in the anterior horizontal direction at the time of right foot contact. An ANOVA summary table for maximum braking force is presented in Table 1. No significant difference was found between the maximum braking forces for the 126 bpm cadence, $M = 41.82$ N, and the 132 bpm cadence, $M = 41.10$ N, $F(1, 44) = 0.01$, $p > .05$. No significant difference was found between the 6-in. step height, M = 59.37 N, and the 8-in. step height, M = 42.75 N, $F(1, 44) = 0.15$, $p > .05$. A significant difference existed among the means for the basic step, M = 39.40 N; the hop step, M = 66.42 N; and the turn step, M = 18.55 N, $F(2, 44) = 16.89$, $p < .05$. The Tukey HSD, $q(3, 44) = 20.09$, $p < .05$, indicated the following pairs of means to be significant: (a) the basic step and the turn step, (b) the hop step and the turn step, and (c) the hop step and the basic step. The first- and second-order interaction effects for the ANOVA were not significant.

Table 1

ANOVA Summary Table for Maximum Braking Force

Source	SS	df	MS	F
Trials	2291.20	4	572.80	0.84
Cadence (C)	7.69	1	7.69	0.01
Height (H)	100.05	1	100.05	0.15
Step (S)	23046.21	2	11523.10	16.89*
C × H	810.49	1	810.49	1.19
C × S	1053.31	2	526.66	0.77
H × S	1810.18	2	905.09	1.33
C × H × S	751.44	2	375.72	0.55
Residual	30010.79	44	682.06	

*Significant at the .05 level.

Horizontal Impulse

Horizontal impulse during braking is the product of the force times time. An ANOVA summary table for horizontal impulse is presented in Table 2. No significant difference was found between the horizontal impulse for the 126 bpm cadence, M = 13.19 Ns, and the 132 bpm cadence, M = 11.79 Ns, $F(1, 44) = 0.0002$, $p > .05$. No significant difference was found between the 6-in. step height, M = 15.43 Ns, and the 8-in. step height, M = 7.61 Ns, $F(1, 44) = 0.95$, $p > .05$. A significant difference existed among the means for the basic step, M = –0.66 Ns; the hop step, M = 3.84 Ns; and the turn step, M = 31.68 Ns, $F(2, 44) = 7.19$, $p < .05$. The Tukey HSD, $q(3, 44) = 20.91$, $p < .05$, indicated the following pairs of means to be significant: (a) turn step and basic step, and (b) hop step and turn step. The first- and second-order interaction effects for the ANOVA were not significant.

Maximum Medial Force

Maximum medial force is the forces acting toward the inside of the respective foot. An ANOVA summary table for maximum medial force is presented in Table 3. No significant difference was found between the maximum medial forces for the 126 bpm cadence, M = 125.23 N, and the 132 bpm cadence, M = 97.80 N, $F(1, 44) = 2.15$, $p > .05$. No significant difference was found between the 6-in. step height, M = 121.80 N, and the 8-in. step height, M = 101.23 N, $F(1, 44) = 1.21$, $p > .05$. A significant difference existed among the means for the basic step, M = 125.80 N; the hop step, M = 49.75 N; and the turn step, M = 159.00 N, $F(2, 44) = 11.97$, $p < .05$. The Tukey HSD, $q(3, 44) = 55.69$, $p < .05$, indicated the following pairs of means to be significant: (a) basic step and hop step, and (b) turn step and hop step. The first- and second-order interaction effects for the ANOVA were not significant.

Table 2

ANOVA Summary Table for Horizontal Impulse

Source	SS	df	MS	F
Trials	4770.26	4	1192.57	1.61
Cadence (C)	0.12	1	0.12	0.00
Height (H)	798.62	1	798.62	0.95
Step (S)	12032.34	2	6016.17	7.19*
C × H	17.17	1	17.17	0.02
C × S	96.16	2	48.08	0.06
H × S	238.12	2	119.06	0.14
C × H × S	440.12	2	220.06	0.26
Residual	36826.57	44	836.97	

*Significant at the .05 level.

Maximum Lateral Force

Maximum lateral force is the greatest forces moving outward to the right for a right foot contact. An ANOVA summary table for maximum lateral force is presented in Table 4. No significant difference was found between the maximum lateral force for the 126 bpm cadence, $\underline{M} = 83.53$ N, and the 132 bpm cadence, $\underline{M} = 97.30$ N, $\underline{F}(1, 44) = 1.02$, $\underline{p} > .05$. No significant difference was found between the 6-in. step height, $\underline{M} = 83.33$ N, and the 8-in. step height, $\underline{M} = 97.50$ N, $\underline{F}(1, 44) =$

1.08, $p > .05$. A significant difference existed among the means of the basic step, M = 57.10 N; the hop step, M = 157.75 N; and the turn step, M = 56.40 N, $F(2, 44) = 24.39$, $p < .05$. The Tukey HSD, $q(3, 44) = 40.62$, $p < .05$, indicated the following pairs of means to be significant different: (a) hop step and turn step, and (b) basic step and hop step. The first- and second-order interaction effects for the ANOVA were not significant.

Table 3

ANOVA Summary Table for Maximum Medial Force

Source	SS	df	MS	F
Trials	24463.90	4	8615.98	1.64
Cadence (C)	11288.82	1	11288.82	2.15
Height (H)	6344.82	1	6344.82	1.21
Step (S)	125476.03	2	62738.02	11.97*
C × H	9702.82	1	9702.82	1.85
C × S	3415.63	2	1707.82	0.33
H × S	5032.03	2	2516.02	0.48
C × H × S	3193.63	2	1596.82	0.30
Residual	230669.30	44	5242.48	

*Significant at the .05 level.

Vertical Impact Force

Vertical impact is the reaction forces in a vertical direction as the foot hit the platform. An ANOVA summary table for vertical impact force is presented in

Table 4

ANOVA Summary Table for Maximum Lateral Force

Source	SS	df	MS	F
Trials	31228.67	4	7807.17	2.80*
Cadence (C)	2842.82	1	2842.82	1.02
Height (H)	3010.42	1	3010.42	1.08
Step (S)	136018.23	2	68009.12	24.39*
C × H	9450.15	1	9450.15	3.39
C × S	3630.43	2	1815.22	0.65
H × S	2284.03	2	1142.02	0.41
C × H × S	6294.90	2	3147.45	1.13
Residual	122696.93	44	2788.57	

*Significant at the .05 level.

Table 5. No significant difference was found between the vertical impact forces for the 126 bpm cadence, M = 585.43 N, and the 132 bpm cadence, M = 539.90 N, $F(1, 44) = 0.45$, $p > .05$. No significance difference was found between the 6-in. step height, M = 574.20 N, and the 8-in. step height, M = 551.13 N, $F(1, 44) = 0.12$, $p > .05$. A significant difference was found among the means of the basic step, M = 346.80 N; hop step, M = 826.10 N; and turn step, M = 515.10 N, $F(2, 44) = 17.05$, $p < .05$. A significant first-order interaction effect for cadence by step height was found, $F(2, 44) = 4.64$, $p < .05$. All other first-order interaction effects were not significant. The second-order interaction effect for cadence by step height, by steps was significant, $F(2, 44) = 5.30$, $p < .05$. A simple simple main effects test was

Table 5

ANOVA and Simple Simple Main Effects Summary for Vertical Impact Force

Source	SS	df	MS	F
Trials	898430.00	4	224607.50	3.24*
Cadence (C)	31099.27	1	31099.27	0.45
Height (H)	7981.07	1	7981.07	0.12
Step (S)	2365162.53	2	1182581.27	17.05*
C × H	321787.27	1	321787.27	4.64*
C × S	96138.13	2	48069.07	0.69
H × S	241168.53	2	120584.27	1.74
C × H × S	734740.00	2	367370.47	5.30*
H at 126 basic	980.10	1	980.10	0.01
H at 126 hop	275560.00	1	275560.00	3.97
H at 126 turn	96432.40	1	96432.40	1.39
H at 132 basic	4796.10	1	4796.10	0.07
H at 132 hop	854977.60	1	854977.60	12.33*
H at 132 turn	72931.60	1	72931.60	1.05
S at 6 in. at 126	846314.80	2	423157.40	6.10*
S at 6 in. at 132	170916.40	2	85458.20	1.23
S at 8 in. at 126	136380.13	2	68190.07	0.98
S at 8 in. at 132	2283598.80	2	1141799.40	16.46*
C at 6 in. basic	916670.40	1	916670.40	13.22*
C at 8 in. hop	386122.50	1	386122.50	5.57*
C at 6 in. turn	44488.90	1	44488.90	0.64

Table 5—Continued

Source	SS	df	MS	F
C at 6 in. basic	32035.60	1	32035.60	0.46
C at 8 in. hop	685916.10	1	685916.10	9.89*
C at 8 in. turn	29052.10	1	29052.10	0.42
Residual	3051373.60	44	69349.40	

*Significant at the .05 level.

calculated to analyze this significant interaction effect. The results of this analysis is presented in Table 5. The significant results of the simple simple main effects were as follows:

1. A significant difference between step heights was found at the 132 bpm cadence for the hop step, $F(1, 44) = 12.33$, $p < .05$. The means for the 6-in. and 8-in. step heights were 566.40 N and 1151.20 N, respectively.

2. A significant difference among steps was found for the 6-in. step height, and the 126 bpm, $F(2, 44) = 6.10$, $p < .05$. The means for the basic, hop, and turn step were 377.6 N, 959.4 N, and 673.6 N, respectively. The Tukey HSD, $q(3, 44) = 202.6$, $p < .05$, indicated the following pairs of means to be significantly different: (a) hop step and basic step, and (b) turn step and the basic step.

3. A significant difference among steps was found at the 8-in. step height for the 132 bpm cadence, $F(2, 44) = 16.46$, $p < .05$. The means for the basic, hop, and turn steps for the 8-in., 132 bpm cadence were 284.20 N, 1151.20 N, and 369.40 N, respectively. The Tukey HSD, $q(3, 44) = 202.6$, $p < .05$, indicated the following pairs

of means to be significantly different: (a) basic step and hop step, and (b) turn step and the hop step.

4. A significant difference between cadences was found at the 6-in. step height for the basic step, $F(1, 44) = 13.22$, $p < .05$. The means for the 126 and 132 cadences were 377.60 N, and 328.00 N, respectively.

5. A significant difference between cadences was found at the 6-in. step height for the hop step, $F(1, 44) = 5.57$, $p < .05$. The means for the 126 bpm and 132 bpm cadences were 959.4 N, and 566.4 N, respectively.

6. A significant difference between cadences was found at the 8-in. step height for the hop step, $F(1, 44) = 9.89$, $p < .05$. The means for the 126 bpm and the 132 bpm cadences were 627.40 N and 1151.20 N, respectively.

Time of Vertical Impact

Time of vertical impact is the time it took to reach maximum vertical force. An ANOVA summary table for times of vertical impact is presented in Table 6. No significant difference was found in the time of vertical impact for the 126 bpm cadence, $M = 0.21$ s, and the 132 bpm cadence, $M = 0.17$ s, $F(1, 44) = 1.34$, $p > .05$. A significant difference was found between the 6-in. step height, $M = 0.27$ s, and the 8-in. step height, $M = 0.11$ s, $F(1, 44) = 18.76$, $p < .05$. A significant difference existed between the means of the basic step, $M = 0.27$ s; the hop step, $M = 0.03$ s; and the turn step, $M = 0.28$ s, $F(2, 44) = 16.97$, $p < .05$. Only one first-order interaction effects was significant, height by step, $F(2, 44) = 6.25$, $p < .05$. The second-order interaction effect for the ANOVA was not significant. A simple main effects test was calculated to analyze the first-order interaction effect. The results of this analysis are presented in Table 6. The significant results of the simple main effects were as follows:

1. A significant difference between heights was found for the basic step, $F(1, 44) = 29.0$, $p < .05$. The means for the 6-in. and 8-in. step heights were 0.70 s and 0.36 s, respectively.

Table 6

ANOVA and Simple Main Effects Summary for Time of Vertical Impact

Source	SS	df	MS	F
Trials	0.15	4	0.04	2.00
Cadence (C)	0.03	1	0.03	1.34
Height (H)	0.42	1	0.42	18.76*
Step (S)	0.76	2	0.38	16.97*
C × H	0.04	1	0.04	1.79
C × S	0.01	2	0.01	0.45
H × S	0.28	2	0.14	6.25*
H at basic	0.58	1	0.58	29.00*
H at hop	0.00	1	0.00	0.00
H at turn	2.19	1	2.19	109.50*
S at 6 in.	3.67	2	1.84	92.00*
S at 8 in.	0.46	2	0.23	11.50*
C × H × S	0.03	2	0.01	0.45
Residual	0.99	44	0.02	

*Significant at the .05 level.

2. A significant difference between heights was found for the turn step, $F(1, 44) = 109.5$, $p < .05$. The means for the 6-in. and 8-in. step heights were 0.87 s and 0.21 s, respectively.

3. A significant difference among steps was found for the 6-in. step, $F(2, 44) = 92.0$, $p < .05$. The means for the basic, hop, and turn step were 0.70 s, 0.06 s, and 0.87 s respectively. The Tukey HSD, $q(3, 44) = 0.11$, $p < .05$, indicated the following pairs of means to be significant: (a) the basic step and the hop step, (b) the turn step and the basic step, and (c) the hop step and the turn step.

4. A significant difference among steps was found at the 8-in. step height, $F(2, 44) = 11.5$, $p < .05$. The means for the basic, hop, and turn step were 0.36 s, 0.06 s, and 0.21 s, respectively. The Tukey HSD, $q(3, 44) = 0.11$, $p < .05$, indicated the following pairs of means to be significant: (a) hop step and basic step, (b) turn step and basic step, and (c) turn step and hop step.

Vertical Loading Rate

Vertical loading rate is the speed at which downward forces were created. An ANOVA summary table for vertical loading rate is presented in Table 7. No significant difference was found in the vertical loading rates between the 126 bpm cadence, M = 7487.37 N/s, and the 132 bpm cadence, M = 11213.80 N/s, $F(1, 44) = 1.66$, $p > .05$. No significant difference was found between the 6-in. step height, M = 6598.87 N/s, and the 8-in. step height, M = 12102.30 N/s, $F(1, 44) = 3.62$, $p > .05$. A significant difference existed among the means of the basic step, M = 3205.50 N/s; the hop step, M = 20216.50 N/s; and the turn step, M = 4629.75 N/s, $F(2, 44) = 14.19$, $p < .05$. The Tukey HSD, $q(3, 44) = 8770.31$, $p < .05$, indicated the following pairs of means to be significant: (a) basic step and hop step, and (b) turn step and hop step. The first- and second-order interaction effects for the ANOVA were not significant.

Table 7

ANOVA Summary Table for Vertical Loading

Source	SS	df	MS	F
Trials	8.2×10^{8}	4	2.1×10^{8}	1.58
Cadence (C)	2.1×10^{8}	1	2.1×10^{8}	1.66
Height (H)	4.5×10^{8}	1	4.5×10^{8}	3.62
Step (S)	3.6×10^{9}	2	1.8×10^{9}	14.19*
C × H	1.8×10^{8}	1	1.8×10^{8}	1.40
C × S	3.7×10^{8}	2	1.8×10^{8}	1.47
H × S	6.3×10^{8}	2	3.1×10^{8}	2.51
C × H × S	2.2×10^{8}	2	1.1×10^{8}	0.87
Residual	5.5×10^{9}	44	1.3×10^{8}	

*Significant at the .05 level.

Maximum Positive Torque

Maximum positive torque is the maximum amount of rotational forces or torsion in the positive direction. The positive direction represented medial rotation of the plant foot for this study. An ANOVA summary table for maximum positive torque is presented in Table 8. No significant difference was found in the maximum positive torque between the 126 bpm cadence, $M = 9.25$ Nm, and the 132 bpm cadence, $M = 18.87$ Nm, $F(1, 44) = 1.10$, $p > .05$. No significant difference was found between the 6-in. step height, M = 11.02, and the 8-in. step height, M = 17.10, $F(1, 44) = 0.44$, $p > .05$. No significant difference existed among the means of the basic step, M = 8.08 Nm; the hop step, M = 27.21 Nm; and the turn step, M = 6.90 Nm, $F(2, 44) = 2.06$, $p > .05$. The first- and second-order interaction effects for the ANOVA were not significant.

Table 8

ANOVA Summary Table for Maximum Positive Torque

Source	SS	df	MS	F
Trials	5271.88	4	1317.97	1.04
Cadence (C)	1388.17	1	1388.17	1.10
Height (H)	555.71	1	555.71	0.44
Step (S)	5197.77	2	2598.89	2.06
C × H	1168.65	1	1168.65	0.93
C × S	2269.01	2	1134.51	0.90
H × S	3092.63	2	1546.32	1.22
C × H × S	3497.79	2	1748.90	1.39
Residual	55556.20	44	1262.64	

*Significant at the .05 level.

Maximum Negative Torque

Maximum negative torque is the maximum amount of rotational forces or torsion in the negative direction during foot contact. The negative direction represented lateral rotation of the plant foot for this study. An ANOVA summary table for maximum negative torque is presented in Table 9. No significant difference was found in the maximum negative torques between the 126 bpm cadence, M = 9.27 Nm, and the 132 bpm cadence, M = 8.66 Nm, $F(2, 44) = 0.17$, $p > .05$. No significant difference was found between the 6-in. step height, M = 8.96 Nm, and the 8-in. step height, M = 9.37 Nm, $F(1, 44) = 0.00$, $p > .05$. A significant difference existed among the means of the basic step, M = 9.37 Nm; the hop step, M = 13.60 Nm; and the turn step, M = 3.93 Nm, $F(2, 44) = 14.31$, $p < .05$. The Tukey HSD, $q(3, 44) = 4.41$, $p < .05$, indicated the following pairs of means to be significant: (a) the basic step and the turn step, and (b) the hop step and the turn step. The first- and second-order interaction effects for the ANOVA were not significant.

Table 9

ANOVA Summary Table for Maximum Negative Torque

Source	SS	df	MS	F
Trials	451.08	4	112.77	3.43*
Cadence (C)	5.52	1	5.52	0.17
Height (H)	0.00	1	0.00	0.00
Step (S)	939.97	2	469.98	14.31*
C × H	74.82	1	74.82	2.28
C × S	75.34	2	37.67	1.15
H × S	77.67	2	38.83	1.18
C × H × S	135.06	2	67.53	2.06
Residual	1445.23	44	32.85	

*Significant at the .05 level.

Electromyography

Peak EMG for the Vastus Lateralis

Peak EMG for the vastus lateralis is the maximum microvolts produced from the time of foot plant to the end of foot contact. An ANOVA summary table for peak EMG for the vastus lateralis is presented in Table 10. No significant difference was found in the peak EMG between the 126 bpm cadence, $\underline{M} = 266.10$ µv, and the 132 bpm cadence, $\underline{M} = 239.50$ µv, $\underline{F}(1, 44)$, = 0.97, $\underline{p} > .05$. A significant difference was found between the 6-in. step height, $\underline{M} = 236.37$ µv, and the 8-in. step height, $\underline{M} = 319.23$ µv, $\underline{F}(1, 44) = 12.22$, $\underline{p} < .05$. No significant difference existed among the means of the basic step, $\underline{M} = 273.20$ µv; the hop step, $\underline{M} = 281.30$ µv; and the turn step, $\underline{M} = 278.90$ µv, $\underline{F}(2, 44) = 0.04$, $\underline{p} > .05$. One first-order interaction effect for step height by step was significant, $\underline{F}(2, 44) = 3.67$, $\underline{p} < .05$. The second-order interaction effect was not significant for the ANOVA. A simple main effects test was calculated to analyze the significant interaction effect. The significant results of the simple main effects were as follows:

1. A significant difference was found between the step heights at the basic step, $\underline{F}(1, 44) = 38.26$, $\underline{p} < .05$. The means for the 6- and 8-in. step heights were 419.4 µv, and 673.4 µv, respectively.

2. A significant difference was found between the step heights at the turn step, $\underline{F}(1, 44) = 39.85$, $\underline{p} < .05$. The means for the 6- and 8-in. step heights were 428.2 µv, and 687.4 µv, respectively.

3. A significant difference was found among the steps at the 6-in. step height, $\underline{F}(2, 44) = 8.54$, $\underline{p} < .05$. The means for the basic, hop, and turn steps were 419.4 µv, 570.6 µv, and 428.2 µv, respectively. The Tukey HSD, $\underline{q}(3, 44) = 70.63$, $\underline{p} < .05$,

indicated the following pairs of means to be significant: (a) the basic step and hop step, and (b) the hop step and turn step.

Table 10

ANOVA and Simple Main Effects Summary for Peak EMG for the Vastus Lateralis

Source	SS	df	MS	F
Trial	93256.18	4	23314.04	2.77*
Cadence (C)	8211.06	1	8211.06	0.97
Height (H)	102994.98	1	102994.98	12.22*
Step (S)	693.32	2	346.66	0.04
C × H	3648.84	1	3648.84	0.43
C × S	27155.22	2	13577.61	1.61
H × S	61938.12	2	30969.06	3.67*
H at basic	322529.20	1	322529.20	38.26*
H at hop	1280.00	1	1280.00	0.15
H at turn	335923.20	1	335923.20	39.85*
S at 6 in.	144055.47	2	72027.74	8.54*
S at 8 in.	106470.30	2	53235.15	6.31*
C × H × S	8646.90	2	4323.45	0.51
Residual	370936.74	44	8430.38	

*Significant at the .05 level.

4. A significant difference was found among the steps at the 8-in. step height, $F(2, 44) = 6.31$, $p < .05$. The means for the basic, hop, and turn steps were 673.4 μv,

554.6 μv, and 687.4 μv, respectively. The Tukey HSD, $q(3, 44) = 70.63$, $p < .05$, indicated the following pairs of means to be significant: (a) basic step and hop step, (b) basic step and turn step, and (c) turn step and hop step.

Peak EMG for the Rectus Femoris

Peak EMG for the rectus femoris measured the maximum microvolts (μv) elicited by the rectus femoris from the time of foot plant to the end of braking. An ANOVA summary table for peak EMG for the rectus femoris is presented in Table 11. A significant difference was found between the 126 bpm cadence, $M = 143.17$ μv, and the 132 bpm cadence, $M = 191.64$ μv, $F(1, 44) = 12.92$, $p < .05$. A significant difference was found between the 6-in. step height, $M = 153.80$ μv, and the 8-in. step height, $M = 181.00$ μv, $F(1, 44) = 4.07$, $p < .05$. A significant difference existed among the means of the basic step, $M = 137.41$ μv; the hop step, $M = 197.65$ μv; and the turn step, $M = 167.15$ μv, $F(2, 44) = 6.65$, $p < .05$. The Tukey HSD, $q(3, 44) = 40.17$, $p < .05$, indicated a significant difference between the means of the basic step and the hop step. The first- and second-order interaction effects for the ANOVA were not significant.

Peak EMG of the Vastus Medialis

Peak EMG of the vastus medialis measured the maximum microvolts expended by the vastus medialis from the time of foot plant to the end of braking. An ANOVA summary table for peak EMG for the vastus medialis is presented in Table 12. A significant difference existed in the peak EMG of the vastus medialis between the 126 bpm cadence, $M = 115.63$ μv, and the 132 bpm cadence, $M = 227.03$ μv, $F(1, 44) = 8.14$, $p < .05$. A significant difference existed between the 6-in. step

Table 11

ANOVA Summary Table for Peak EMG for the Rectus Femoris

Source	SS	df	MS	F
Trial	5081.44	4	1270.36	1.86
Cadence (C)	35240.11	1	35240.11	12.92*
Height (H)	11100.32	1	11100.32	4.07*
Step (S)	36296.50	2	18148.25	6.65*
C × H	14.90	1	14.90	0.01
C × S	6063.97	2	3031.98	1.11
H × S	20533.04	2	10266.52	3.76
C × H × S	8521.12	2	4260.56	1.56
Residual	119990.72	44	2727.06	

*Significant at the .05 level.

height, M = 102.53 µv, and the 8-in. step height, M = 240.13 µv, $F(1, 44) = 12.41$, $p < .05$. A significant difference existed among the means of the basic step, M = 104.85 µv; hop step, M = 267.95 µv; and the turn step, M = 141.20 µv, $F(2, 44) = 6.41$, $p < .05$. Significant differences existed for the first-order interaction effects step height by cadence, $F(2, 44) = 8.63$, $p < .05$, cadence by step, $F(2, 44) = 4.38$, $p < .05$, and step height by steps, $F(2, 44) = 4.39$, $p < .05$. A significant second-order interaction effect cadence by step height by steps was found, $F(2, 44) = 4.83$, $p < .05$. A simple simple main effects test was calculated to analyze this significant second-order interaction effect. The results of this analysis are presented in Table 12. The significant results of the simple simple main effects were as follows:

Table 12

ANOVA and Simple Simple Main Effects Summary
for Peak for the EMG Vastus Medialis

Source	SS	df	MS	F
Trials	134468.17	4	33617.04	1.47
Cadence (C)	186149.40	1	186149.40	8.14*
Height (H)	284006.40	1	284006.40	12.41*
Step (S)	293256.63	2	146628.32	6.41*
C × H	197456.07	1	197456.07	8.63*
C × S	200256.70	2	100128.35	4.38*
H × S	200982.90	2	100491.45	4.39*
C × H × S	221061.63	2	110530.82	4.83*
H at 126 basic	5808.10	1	5808.10	0.25
H at 126 hop	705.60	1	705.60	0.03
H at 126 turn	32.40	1	32.40	0.00
H at 132 basic	10112.40	1	10112.40	0.44
H at 132 hop	857904.10	1	857904.10	37.49*
H at 132 turn	28944.40	1	28944.40	1.36
S at 6 in. 126	9612.40	2	4806.20	0.21
S at 6 in. 132	1938.53	2	969.27	0.04
S at 8 in. 126	1270.53	2	635.27	0.03
S at 8 in. 132	902736.40	2	451368.20	19.73*
C at 6 in. basic	722.50	1	722.50	0.03
C at 6 in. hop	240.10	1	240.10	0.01

Table 12—Continued

Source	SS	df	MS	F
C at 6 in. turn	739.60	1	739.60	0.03
C at 8 in. basic	2624.40	1	2624.40	0.12
C at 8 in. hop	781761.60	1	781761.60	34.16*
C at 8 in. turn	18835.60	1	18835.60	0.82
Residual	1006827.43	44	22882.44	

*Significant at the .05 level.

1. A significant difference between step heights was found at the 132 bpm cadence for the hop step, $F(1, 44) = 37.49$, $p < .05$. The means for the 6-in. and 8-in. step heights were 112.40 μv and 698.20 μv, respectively.

2. A significant difference among steps was found at the 8-in step height for the 132 bpm cadence, $F(2, 44) = 19.73$, $p < .05$. The means for the basic, hop, and turn steps were 149.00 μv, 698.20 μv, and 121.40 μv, respectively. The Tukey HSD, $q(3, 44) = 116.36$, $p < .05$, indicated the following pairs of means to be significantly different: (a) basic step and the hop step, and (b) turn step and hop step.

3. A significant difference between cadence was found at the 8-in. step height for the hop step, $F(1, 44) = 34.16$, $p < .05$. The means for the 126 bpm and the 132 bpm cadences were 139.00 μv and 698.20 μv, respectively.

Time to Peak for the Vastus Lateralis

Time to peak muscle recruitment for the vastus lateralis is the elapsed time from foot plant to peak EMG. An ANOVA summary table for the time to peak recruitment for the vastus lateralis is presented in Table 13. No significant difference was found in time to peak recruitment between the 126 bpm cadence, M = 195.79 ms, and the 132 bpm, M = 141.50 ms, $F(1, 44) = 0.93$, $p > .05$. No significant difference was found between the 6-in. step height, M = 126.68 ms, and the 8-in. step height, M = 210.61 ms, $F(1, 44) = 2.21$, $p > .05$. No significant difference was found among the means for the basic step, M = 142.02 ms; hop step, M = 201.45 ms; and the turn step, M = 162.47 ms, $F(2, 44) = 0.38$, $p > .05$. The first- and second-order interaction effects for the ANOVA were not significant.

Table 13

ANOVA Summary Table for Time to Peak for the Vastus Lateralis

Source	SS	df	MS	F
Trial	188614.42	4	47153.61	0.99
Cadence (C)	44200.21	1	44200.21	0.93
Height (H)	105680.46	1	105680.46	2.21
Step (S)	36469.11	2	18234.56	0.38
C × H	40888.26	1	40888.26	0.86
C × S	86769.24	2	43384.62	0.91
H × S	36363.67	2	18181.83	0.38
C × H × S	70410.93	2	35205.47	0.74
Residual	2099580.23	44	47717.73	

*Significant at the .05 level.

Time to Peak EMG for the Rectus Femoris

Time to peak muscle recruitment for the rectus femoris is the elapsed time from foot plant to peak EMG. An ANOVA summary table for time to peak EMG for the rectus femoris is presented in Table 14. No significant difference was found in the time to peak EMG for the rectus femoris between the 126 bpm cadence, M = 168.59 ms, and the 132 bpm cadence, M = 141.00 ms, $F(1, 44) = 0.41$, $p > .05$. No significant difference existed between the 6-in. step height, M = 134.07 ms, and the 8-in. step height, M = 175.52 ms, $F(1, 44) = 0.92$, $p > .05$. No significant difference existed between the means of the basic step, M = 189.71 ms; the hop step, M = 167.92 ms; and the turn step, M = 106.76 ms, $F(2, 44) = 1.32$, $p > .05$. The first- and second-order interaction effects for the ANOVA were not significant.

Time to Peak EMG for the Vastus Medialis

Time to peak EMG for the vastus medialis is the elapsed time from the time of foot plant to peak EMG. An ANOVA summary table for time to peak EMG for the vastus medialis is presented in Table 15. No significant difference was found in the time to peak EMG for the vastus medialis between the 126 bpm cadence, M = 168.18 ms, and the 132 bpm cadence, M = 209.51 ms, $F(1, 44) = 0.83$, $p > .05$. A significant difference was found between the 6-in. step height, M = 108.45 ms, and the 8-in. step height, M = 269.24 ms, $F(1, 44) = 12.56$, $p < .05$. A significant difference existed between the means of the basic step, M = 167.83 ms; the hop step, M = 269.84 ms; and the turn step, M = 128.88 ms, $F(2, 44) = 3.43$, $p < .05$. A significant difference was found for the first-order interaction effect step height by steps, $F(2, 44) = 3.63$, $p < .05$. There was no significant difference found for the

Table 14

ANOVA Summary Table for Time to Peak EMG for the Rectus Femoris

Source	SS	df	MS	F
Trials	106284.68	4	26571.17	0.95
Cadence (C)	11418.12	1	11418.12	0.41
Height (H)	25763.25	1	25763.25	0.92
Step (S)	73971.06	2	36985.53	1.32
C × H	6134.75	1	6134.75	0.22
C × S	659.03	2	329.51	0.01
H × S	106097.76	2	53048.88	1.89
C × H × S	18049.95	2	9024.98	0.32
Residual	1233320.76	44	28030.02	

*Significant at the .05 level.

other first- and second-order interaction effects in this ANOVA. A simple main effects test was calculated to analyze the significant first-order interaction effect. The results of this analysis are presented in Table 15. The significant results of the simple main effects were as follows:

1. A significant difference between step heights was found for the hop step, $F(1, 44) = 72.11$, $p < .05$. The means for the 6-in. and 8-in. step heights were 205.9 ms and 873.4 ms, respectively.

2. A significant difference among the steps at the 8-in. step height existed, $F(2, 44) = 27.74$, $p < .05$. The means for the basic, hop, and turn steps were 411.2 ms, 873.4 ms, and 330.9 ms, respectively. The Tukey HSD, $q(3, 44) = 135.19$,

Table 15

ANOVA and Simple Main Effects Summary for
Time to Peak EMG for the Vastus Medialis

Source	SS	df	MS	F
Trials	163198.30	4	40799.57	1.32
Cadence (C)	25630.80	1	25630.80	0.83
Height (H)	387833.51	1	387833.51	12.56*
Step (S)	211952.43	2	105976.21	3.43*
C × H	106420.39	1	106420.39	3.45
C × S	77469.79	2	38734.89	1.25
H × S	224309.41	2	112154.70	3.63*
H at basic	114156.05	1	114156.05	3.70
H at hop	2227514.26	1	2227514.26	72.11*
H at turn	106609.20	1	106609.20	3.45
S at 6 in.	30141.94	2	15070.17	0.49
S at 8 in.	1713453.65	2	856726.83	27.74*
C × H × S	49712.85	2	24856.42	0.80
Residual	1359120.87	44	30889.11	

*Significant at the .05 level.

$p < .05$, indicated the following pairs of means to be significantly different: (a) basic step and the hop step, and (b) turn step and hop step.

Area Under the Curve for the Vastus Lateralis

Area under the curve for the vastus lateralis is the product of microvolts times time. Area is measured from the time of foot plant until the end of foot contact. An ANOVA summary table for the area under the curve of the vastus lateralis is presented in Table 16. No significant difference was found for the area under the curve between the 126 bpm cadence, $\underline{M} = 73.42$ µv•ms, and the 132 bpm cadence, $\underline{M} = 72.88$ µv•ms, $\underline{F}(1, 44) = 0.05$, $\underline{p} > .05$. A significant difference existed between the means of the 6-in. step height, $\underline{M} = 68.40$ µv•ms, and the 8-in. step height, $\underline{M} = 77.90$ µv•ms, $\underline{F}(1, 44) = 13.81$, $\underline{p} < .05$. A significant difference existed among the means of the basic step, $\underline{M} = 56.73$ µv•ms; the hop step, $\underline{M} = 94.32$ µv•ms; and the turn step, $\underline{M} = 68.40$ µv•ms, $\underline{F}(2, 44) = 75.60$, $\underline{p} < .05$. The first-order interaction effect step height by steps was significant, $\underline{F}(2, 44) = 15.03$, $\underline{p} < .05$. The other first- and second-order interaction effects for the ANOVA were not significant. A simple main effects test was calculated to analyze the significant first-order interaction effect. The results of this analysis are presented in Table 16. The significant results of the simple main effects were as follows:

1. A significant difference between step heights was found for the basic step, $\underline{F}(1, 44) = 71.65$, $\underline{p} < .05$. The means for the 6-in. and 8-in. step height were 189.44 µv•ms and 264.37 µv•ms, respectively.

2. A significant difference between step heights was found for the hop step, $\underline{F}(1, 44) = 21.66$, $\underline{p} < .05$. The means for the 6-in. and 8-in. step heights were 397.88 µv•ms and 356.68 µv•ms, respectively.

Table 16

ANOVA and Simple Main Effects Summary for the Area Under the Curve for the Vastus Lateralis

Source	SS	df	MS	F
Trials	194.56	4	48.64	0.50
Cadence (C)	4.53	1	4.53	0.05
Height (H)	1352.99	1	1352.99	13.81*
Step (S)	14809.58	2	7404.79	75.60*
C × H	357.61	1	357.61	3.65
C × S	129.08	2	64.54	0.66
H × S	2943.92	2	1471.96	15.03*
H at basic	7017.76	1	7017.76	71.65*
H at hop	2121.80	1	2121.80	21.66*
H at turn	8048.07	1	8048.07	82.17*
S at 6 in.	60345.10	2	30172.55	308.04*
S at 8 in.	10668.91	2	5334.45	54.46*
C × H × S	180.24	2	90.12	0.92
Residual	4309.72	44	97.95	

*Significant at the .05 level.

3. A significant difference between step heights was found for the turn step, $F(1, 44) = 82.17$, $p < .05$. The means for the 6-in. and 8-in. step heights were 233.48 µv•ms and 934.77 µv•ms, respectively.

4. A significant difference among steps was found for the 6-in. step height, $F(2, 44) = 308.04$, $p < .05$. The means for the basic, hop, and turn steps were 189.44 µv•ms, 397.88 µv•ms, and 233.48 µv•ms, respectively. The Tukey HSD, $q(3, 44) = 7.61$, $p < .05$, indicated the following pairs of means to be significantly different: (a) basic step and hop step, (b) basic step and turn step, and (c) hop step and turn step.

5. A significant difference among steps was found for the 8-in. step height, $F(2, 44) = 54.46$, $p < .05$. The means for the basic, hop, and turn steps were 264.37 µv•ms, 356.68 µv•ms, 934.77 µv•ms, respectively. The Tukey HSD, $q(3, 44) = 7.61$, $p < .05$, indicated the following pairs of means to be significantly different: (a) basic step and hop step, (b) basic step and turn step, and (c) turn step and hop step.

Area Under the Curve for the Rectus Femoris

Area under the curve for the rectus femoris is the product of microvolts times time. Area is measured from the time of foot plant until the end of braking. An ANOVA summary table for area under the curve for the rectus femoris is presented in Table 17. A significant difference was found in the area under the curve between the 126 bpm cadence, $M = 47.68$ µv•ms, and the 132 bpm cadence, $M = 54.60$ µv•ms, $F(1, 44) = 10.30$, $p < .05$. No significant difference was found between the 6-in. step height, $M = 49.29$ µv•ms, and the 8-in. step height, $M = 52.98$ µv•ms, $F(1, 44) = 2.91$, $p > .05$. A significant difference existed among the means of the basic step, $M = 37.51$ µv•ms; the hop step, $M = 73.75$ µv•ms; and the turn step, $M = 42.16$ µv•ms, $F(2, 44) = 111.66$, $p < .05$. Significant differences were found for the first-order interaction effects cadence by step height, $F(2, 44) = 10.43$, $p < .05$, and step height by steps, $F(2, 44) = 14.1$, $p < .05$. The second-order interaction effect for the ANOVA was not significant. A simple main effects test was calculated to analyze the significant first-order interaction effect. The results of this analysis are presented in Table 17. The significant results of the simple main effects were as follows:

1. A significant difference between step heights was found for the basic step, $F(1, 44) = 38.42$, $p < .05$. The means for the 6-in. and 8-in. step heights were 126.9 µv•ms, and 173.2 µv•ms, respectively.

2. A significant difference between step heights was found for the hop step, $F(1, 44) = 44.88$, $p < .05$. The means for the 6-in. and 8-in. step heights were 320 µv•ms, and 270 µv•ms, respectively.

3. A significant difference between step heights was found for the turn step, $F(1, 44) = 41.09$, $p < .05$. The means for the 6- and 8-in. step heights were 144.7 µv•ms and 192.6 µv•ms, respectively.

4. A significant difference among steps was found at the 6-in. step height, $F(2, 44) = 408.83$, $p < .05$. The means for the basic, hop, and turn steps were 126.90 µv•ms, 320.00 µv•ms, and 144.70 µv•ms, respectively. The Tukey HSD, $q(3, 44) = 6.42$, $p < .05$, indicated the following pairs of means to be significantly different: (a) the hop step and the basic step, (b) the turn step and the basic step, and (c) the turn step and the hop step.

5. A significant difference was found among the steps at the 8-in. step height, $F(2, 44) = 94.22$, $p < .05$. The means for the basic, hop, and turn steps were 173.20 µv•ms, 270.00 µv•ms, and 192.60 µv•ms, respectively. The Tukey HSD, $q(3, 44) = 6.42$, $p < .05$, indicated the following pairs of means to be significantly different: (a) the hop step and the basic step, (b) the turn step and the basic step, and (c) the turn step and the hop step.

Table 17

ANOVA and Simple Main Effects Summary for the Area Under the Curve for the Rectus Femoris

Source	SS	df	MS	F
Trials	54.39	4	13.60	0.20
Cadence (C)	717.33	1	717.33	10.30*
Height (H)	202.62	1	202.62	2.91
Step (S)	15550.95	2	7775.48	111.66*
C × H	726.21	1	726.21	10.43*
H at 126	848.01	1	848.01	12.18*
H at 132	80.85	1	80.85	1.16
C at 6 in.	1443.52	1	1443.52	20.73*
C at 8 in.	0.01	1	0.01	0.00
C × S	329.65	2	164.82	2.37
H × S	1962.70	2	981.35	14.10*
H at basic	2675.45	1	2675.45	38.42*
H at hop	3125.00	1	3125.00	44.88*
H at turn	2860.83	1	2860.83	41.09*
S at 6 in.	56933.17	2	28466.59	408.83*
S at 8 in.	13121.43	2	6560.72	94.22*
C × H × S	279.76	2	139.88	2.01
Residual	3063.82	44	69.63	

*Significant at the .05 level.

Area Under the Curve for the Vastus Medialis

Area under the curve for the vastus medialis is the product of microvolts times time. Area was measured from the time of foot plant until the end of foot contact. An ANOVA summary table for the area under the curve for the vastus medialis is presented in Table 18. A significant difference was found in the area under the curve between the 126 bpm cadence, $\underline{M}$ = 41.16 μv•ms, and the 132 bpm cadence, $\underline{M}$ = 53.71 μv•ms, $\underline{F}(1, 44) = 4.95$, $\underline{p} < .05$. A significant difference existed between the 6-in. step height, $\underline{M}$ = 38.24 μv•ms, and the 8-in. step height, $\underline{M}$ = 56.62 μv•ms, $\underline{F}(1, 44) = 10.62$, $\underline{p} < .05$. A significant difference existed among the means of the basic step, $\underline{M}$ = 32.08 μv•ms; the hop step, $\underline{M}$ = 73.88 μv•ms; and the turn step, $\underline{M}$ = 36.35 μv•ms, $\underline{F}(2, 44) = 22.19$, $\underline{p} < .05$. A significant difference was found for the first-order interaction effects cadence by step height, $\underline{F}(2, 44) = 5.52$, $\underline{p} < .05$, and cadence by steps, $\underline{F}(2, 44) = 6.28$, $\underline{p} < .05$. The second-order interaction effect for the ANOVA was not significant. A simple main effects test was calculated to analyze the significant first-order interaction effects. The results of this analysis is presented in Table 18. The significant results of the simple main effects tests were as follows:

1. A significant difference between cadences was found at the hop step, $\underline{F}(1, 44) = 69.80$, $\underline{p} < .05$. The means for the 126 bpm and the 132 bpm cadence were 213.90 μv•ms and 377.10 μv•ms, respectively.

2. A significant difference among steps was found at the 126 bpm cadence, $\underline{F}(2, 44) = 9.84$, $\underline{p} < .05$. The means for the basic, hop, and turn steps were 132.50 μv•ms, 213.90 μv•ms, and 147.60 μv•ms, respectively. The Tukey HSD, $\underline{q}(3, 44) = 16.80$, $\underline{p} < .05$, indicated the following pairs of means to be significantly different: (a) the basic step and hop step, and (b) the hop step and turn step.

Table 18

ANOVA and Simple Main Effects Summary for the Area Under the Curve for the Vastus Medialis

Source	SS	df	MS	F
Trials	2170.33	4	542.58	1.14
Cadence (C)	2359.40	1	2359.40	4.95*
Height (H)	5064.61	1	5064.61	10.62*
Step (S)	21156.07	2	10578.04	22.19*
C × H	2632.78	1	2632.78	5.52*
H at 126	1774.08	1	1774.08	3.72
H at 132	67502.38	1	67502.38	141.59*
C at 6 in.	33.71	1	33.71	0.07
C at 8 in.	44895.88	1	44895.88	94.17*
C × S	5987.29	2	2993.64	6.28*
C at basic	86.94	1	86.94	0.18
C at hop	33276.48	1	33276.48	69.80*
C at turn	23.33	1	23.33	0.05
S at 126	9386.27	2	4693.14	9.84*
S at 132	99187.17	2	49593.58	104.03*
H × S	2619.54	2	1309.77	2.75
C × H × S	3732.76	2	1866.38	3.91
Residual	20976.43	44	476.74	

*Significant at the .05 level.

3. A significant difference among steps was found at the 132 bpm cadence, $\underline{F}(2, 44) = 104.03$, $\underline{p} < .05$. The means for the basic, hop, and turn steps were 124.10 μv•ms, 377.10 μv•ms, and 143.20 μv•ms, respectively. The Tukey HSD, $\underline{q}(3, 44) = 16.80$, $\underline{p} < .05$, indicated the following pairs of means to be significant differently: (a) the basic step and the hop step, and (b) hop step and turn step.

4. A significant difference between heights was found at the 132 bpm cadence, $\underline{F}(1, 44) = 141.59$, $\underline{p} < .05$. The means for the 6-in. and 8-in. step heights were 113.70 μv•ms and 208.60 μv•ms, respectively.

5. A significant difference between cadences was found at the 8-in. step height, $\underline{F}(1, 44) = 94.17$, $\underline{p} < .05$. The means for the 126 bpm and the 132 bpm cadences were 131.20 μv•ms and 208.60 μv•ms, respectively.

Center of Gravity Displacement

Sagittal Plane Center of Gravity Displacement

The center of gravity was measured during right foot contact. It was determined by analyzing 20 anatomical points. An ANOVA summary table for sagittal plane center of gravity displacement is presented in Table 19. A significant difference was found for the center of gravity between 126 bpm cadence, $\underline{M} = 0.18$ m, and the 132 bpm cadence, $\underline{M} = 0.15$ m, $\underline{F}(1, 44) = 11.57$, $\underline{p} < .05$. A significant difference was found between the 6-in. step height, $\underline{M} = 0.18$ m, and the 8-in. step height, $\underline{M} = 0.15$ m, $\underline{F}(1, 44) = 13.01$, $\underline{p} < .05$. A significant difference existed among the means of the basic step, $\underline{M} = 0.20$ m; the hop step, $\underline{M} = 0.06$ m; and the turn step, $\underline{M} = 0.23$ m, $\underline{F}(2, 44) = 244.36$, $\underline{p} < .05$. The Tukey HSD, $\underline{q}(3, 44) = 0.02$, $\underline{p} < .05$, indicated the following pairs of means were significantly different: (a) the basic step and the hop step, (b) the turn step and the hop step, and (c) the turn step and the basic step. The first- and second-order interaction effects for the ANOVA were not significant.

Table 19

ANOVA Summary Table for Sagittal Plane Center of Gravity Displacement

Source	SS	df	MS	F
Trials	3.8×10^{-3}	4	9.6×10^{-4}	1.37
Cadence (C)	8.0×10^{-3}	1	8.0×10^{-3}	11.57*
Height (H)	9.0×10^{-3}	1	9.0×10^{-3}	13.01*
Step (S)	3.4×10^{-1}	2	1.7×10^{-1}	244.36*
C × H	6.0×10^{-5}	1	6.0×10^{-5}	0.09
C × S	$1.3 \times 10^{-}$	2	7.0×10^{-4}	1.01
H × S	$1.7 \times 10^{-}$	2	9.0×10^{-4}	1.30
C × H × S	$2.5 \times 10^{-}$	2	1.3×10^{-3}	1.88
Residual	$3.0 \times 10^{-}$	44	7.0×10^{-4}	

*Significant at the .05 level.

Frontal Plane Center of Gravity Displacement

Center of gravity was measured during the right foot contact. An ANOVA summary table for the frontal plane center of gravity displacement is presented in Table 20. No significant difference was found in the center of gravity for the 126 bpm cadence, M = 0.10 m, and the 132 bpm cadence, M = 0.10 m, $F(1, 44) = 0.19$, $p > .05$. No significant difference was found between the 6-in. step height, M =

0.90 m, and the 8-in. step height, M = 0.11 m, $F(1, 44) = 0.80$, $p > .05$. A significant difference existed among the means of the basic step, M = 0.02 m; the hop step, M = 0.02 m; and the turn step, M = 0.26 m, $F(2, 44) = 174.0$, $p < .05$. The Tukey HSD, $q(3, 44) = 0.01$, $p < .05$, indicated the following pairs of means to be significantly different: (a) the turn step and the basic step, and (b) the turn step and the hop step. The first- and second-order interaction effects for the ANOVA were not significant.

Table 20

ANOVA Summary Table for Frontal Plane Center of Gravity Displacement

Source	SS	df	MS	F
Trials	1.6×10^{-2}	4	4.1×10^{-3}	1.95
Cadence (C)	4.0×10^{-4}	1	4.0×10^{-4}	0.19
Height (H)	1.7×10^{-3}	1	1.7×10^{-3}	0.80
Step (S)	7.4×10^{-1}	2	3.7×10^{-1}	174.00*
C × H	0.00	1	0.00	0.00
C × S	1.6×10^{-3}	2	8.0×10^{-4}	0.38
H × S	4.1×10^{-3}	2	2.1×10^{-3}	0.99
C × H × S	3.0×10^{-4}	2	1.0×10^{-4}	0.05
Residual	9.3×10^{-2}	44	2.1×10^{-3}	

*Significant at the .05 level.

Discussion

The ANOVA calculated for this study for all dependent variables was a randomized block factorial design. This design produces an F ratio that indicates whether the blocks are significantly different from one another. In most studies blocks represent the various subjects who repeat treatments; therefore, the F ratio is expected to be significant between subjects who do not respond in the same manner under the same conditions. However, in this study, a single subject design, the blocks represented trials. Therefore, if the F ratio for blocks was significant, the subject was not consistent from trial to trial. A significant F ratio for blocks or trials for this study was found for the following dependent variables: (a) lateral force, (b) vertical impact, (c) negative torque, and (d) peak EMG for the vastus lateralis. It was believed that these inconsistencies among the 5 trials were due to two facts: the fatigued condition of the subject, and an attempt to keep in step with the music, cadence. According to Newton's law of acceleration, if the movement begins fast, the result will be a greater vertical impact force when the motion is stopped compared to a movement that begins slower. After impact the subject notes the speed of the movement with respect to the cadence of the music and makes adjustments during the time she is in contact with the ground. Therefore, the cadence error occurred because the movement was initiated at a faster speed than necessary for the cadence. The inconsistencies in lateral forces and negative torque are a result of the variations in ground reaction forces made during the propulsion phase of the motion to get back in step with the music.

Ground Reaction Forces

The results showed that for braking force the only variables that were significantly different were the steps: basic, hop, and turn. The hop step produced the greatest amount of braking force when compared with the basic step and turn step. The hop step creates the greatest drive forward at foot contact so therefore should have the greatest braking force to slow down the momentum of the body. The turn step produced the least amount of braking force because once the right foot comes down on the step the motion continues in a medial direction. The braking force for the turn step is less than either the basic step or the hop step; for both the hop and basic steps, the body's forward motion must stop and then reverse direction to complete the movement.

Horizontal anterior/posterior impulse was not significantly different between the hop and the basic steps. When the impulse for both the anterior and posterior directions were summed, the results for both the basic and the hop step were about 0, –0.66 Ns, and 3.84 Ns, respectively. Therefore, about the same impulse was used in both the braking (anterior) and propulsion (posterior) directions. The horizontal impulse for the turn step was significantly greater than 0. The resultant impulse for the turn step acted in the posterior direction and was therefore associated with propulsion. This resultant impulse was caused for several reasons. First, the braking force was smallest for the turn step, 18.55 N, compared to the basic and hop steps, 39.40 N and 66.42 N, respectively. Because impulse in the anterior/posterior directions represented the sum of impulse generated during the braking and propulsion phases, this result would be expected. Second, due to the motion direction of the three steps studied, it would be expected that the turn step would have a different impulse than the basic or the hop steps. In the basic and hop steps the motion direction is always anterior followed by posterior motion; for the turn step the motion is anterior, then medial. The body does not move in a posterior direction until the foot that was studied is off of the force platform. In order to execute the turn in time to the music, the turn foot is planted with minimal anterior force and immediately begins to generate forces that will cause the body to turn to the medial side. Third, it was believed that the plant position of the foot would be different for the turn step compared to the basic or the hop step; however, this was not measured.

The subject was not consistent across trials for the vertical impact force. A second-order interaction effect cadence by step height by step was found. The step height was found to be significantly different for the hop step at the 132 bpm cadence. Step height for the hop step was not, however, found to be significant for the 126 bpm cadence. This indicated that at the faster cadence there was a greater difference between the step heights for the hop. The faster cadence must cause the subject to hop faster, increasing her forces as she lands on the higher step. Also, she may not be able to control the landing as well at the faster speeds which would cause the vertical impact forces to be greater at the 132 bpm cadence for the 8-in. step than for the 6-in. step. For the 6-in. step for 126 bpm cadence, vertical impact was significantly different between the basic step and the hop step and between the basic step and the turn step but not significant between the hop step and the turns step. For the 6-in. step for 132 bpm cadence, vertical impact was not significantly different among the steps. This same pattern did not exist at the 8-in. step. For the 8-in. step for 126 bpm cadence, vertical impact was not significant among the steps. However, for the 8-in. step for 132 bpm cadence, vertical impact was significantly different between the basic step and the hop step and between the hop step and the turn step, but not significant between the basic step and the turn step. The basic and the turn step produced greater vertical impact forces at the 6-in. step at 126 bpm cadence than for the 8-in. step at 132 bpm cadence. This does not agree with the literature which stated that at greater heights and cadences the vertical ground reaction forces were greater. However, related studies tested the forces as the subject stepped off of the step, whereas this study examined the forces as the subject stepped onto the step (Johnson et al., 1993; Moses et al., as cited in Scharff-Olsen et al., 1996). This could also be explained by the subject's inconsistency across trials, which could be due to the fatigued state that she was in at the time of data collection. The hop step was greater for the 8-in. step at 132 bpm cadence than for the 6-in. step at 126 bpm cadence, which agrees with the literature stated above. There was a significant difference in vertical impact for the 126 and 132 bpm cadences at the 6-in. step height for the basic and hop steps. The 126 bpm cadence produced greater vertical impact forces than the 132 bpm cadence at the 6-in. step. It has been reported that as the music speed increases, the participant would not be able to achieve full range of motion for the steps which could explain why she is producing greater forces at the lower speed (Kravitz & Dievert, 1991). She is moving through the movement so quickly at the 132 bpm cadence that she is not fully extending her body before she comes back down, which would cause her to generate less force while on the step. At the 8-in. step, the hop step produced greater forces at the 132 bpm cadence than at the 126 bpm cadence. This agrees with what was stated earlier that there was a significant difference between step heights for the hop.

Time to vertical impact was significantly different between step heights for the basic step and for the turn step but not for the hop step. The means for the 6- and 8-in. step heights were 0.3470 s and 0.1815 s for the basic step, respectively;

0.0306 s and 0.0316 s for the hop step, respectively; and 0.4374 s and 0.1066 s for the turn step, respectively. Time to vertical impact was longer for the 6-in. step height than for the 8-in. step height for both the basic and turn steps. No difference was found between the two step heights for the hop step. The hop step's time would be the same for both heights because the body is a projectile before impact. As a projectile, gravity is controlling the vertical velocity of the body prior to impact. The small differences between the two step heights for the hop indicate that the body's center of gravity was raised about the same height above the step for each step height condition. The differences between step heights for the basic and the turn steps were the same. A smaller time to reach vertical impact was associated with the 8-in. step compared to the 6-in. step. This difference in time could occur because the body moves through a greater range of motion for the 6-in. step height than for the 8-in. step, therefore causing the 6-in. step to take longer to reach maximum vertical impact. The center of gravity data support this conclusion. The subject experienced a significantly greater range of motion in the sagittal plane for the 6-in. step than for the 8-in. step.

The vertical loading rate showed a significant difference between the basic and the hop step, and between the turn and the hop step. The hop step produced a much larger vertical loading rate than either the basic or the turn step. This would be expected due to the ballistic movement of the hop; it is producing such great force in such a short time because the subject is a projectile prior to making contact with the force platform. This supports the hypothesis that stated that the ground reaction forces would be greater for the hop step than for the basic and turn steps; however, it goes against the hypothesis that stated that the turn step and basic step would be different from one another. They were in fact different but not significantly.

The results for vertical ground reaction forces for this study seem to be the opposite of what was found in other studies; however, all other studies looked at the forces stepping down from the step instead of onto the step. Johnson et al. (1993) found that peak vertical ground reaction forces, peak loading rates, and peak vertical impulses increased as the step height went up with the 6-in. step being the lowest. This researcher found the exact opposite for stepping onto the step: the 6-in. step height was greater than the 8-in. step height for each of the forces measured. These results go against the hypothesis that the 8-in. step height would produce greater ground reaction forces than the 6-in. step height. Moses et al. (as cited in Scharff-Olsen et al., 1996) found that the faster cadences produced greater vertical ground reaction force when stepping off of the step, yet this study found the opposite to be true. The 126 bpm cadence produced a greater vertical impact force than the 132 bpm cadence produced. This goes against the hypothesis which suggested that the 132 bpm cadence would produce greater ground reaction forces than the 126 bpm cadence.

Horizontal Ground Reaction Forces

The results for the medial force indicated a significant difference between the basic and hop step, as well as the turn and hop step. The turn step exhibited the greatest amount of medial force because the subject was moving in a medial direction once her foot hit the step. The basic step also had a great amount of medial force because when one foot is on the step, the center of gravity is behind that foot so the body is leaning slightly inward which causes a medial ground reaction force. The hop step had the least amount of medial force because both feet came down together so there should not have been much medial movement. There was no significant difference found for any of the variables for positive torque, which indicates that although there were forces acting inward, they were not significantly different.

There was no consistency across trials for the lateral force. Medial and lateral forces were both significantly different among the steps. For both forces, the hop was significantly different from the basic step and from the turn step. However, no difference was found between the basic and the turn steps. The medial forces were greater for the basic and turn steps than for the hop step. This is due to the nature of the movements. In both the basic and turn steps, the body's weight approaches the step one foot at a time. Thus, the body's weight is partially supported and pushed up onto the step by the opposite foot creating a medial ground reaction force. This is not the case when the body's weight approaches the step as a projectile. As a projectile the body's weight should approach more evenly in the lateral/medial direction. This was true for the hop in the medial direction but not true for the lateral direction. In the lateral direction, a greater force existed for the hop than for the basic or turn steps. This difference was attributed to the subject's externally rotated tibias that will be discussed later.

No significant difference was found between the step heights, cadences, or among the steps for medial torque. However, a significant difference was found between the basic and turns step and between the hop and turn step for lateral torque. This difference is attributed to the turning or twisting motion of the foot to turn the body 90° during the turn step. The hypotheses that suggested that the positive and negative torques would be greater for the turn and basic step than for the hop step were both found to be untrue. The hop step showed the larger positive and negative torque when compared to either the basic or turn step.

Center of Gravity Displacement

The center of gravity displacement in the sagittal plane showed significant differences between the cadences, between heights, and among the steps. A greater center of gravity displacement was seen for the 126 bpm cadence than for the 132 bpm cadence which agrees with Kravitz and Deivert (1991), who claimed that at the faster cadences the body cannot go through its full range of motion. This also agrees with the hypothesis that stated that the center of gravity displacement would be different at the 132 bpm cadence than for the 126 bpm cadence. The two step heights showed a similar pattern; the 6-in. step height had a greater center of gravity displacement than the 8-in. step height. This could be related to range of motion. At the 8-in. step the subject may not have time to move through a full range of motion on each step before descending. This supports the hypothesis that there would be a difference between the 8- and 6-in. step heights for center of gravity displacement. The basic and the hop steps had similar means but the hop step showed very little center of gravity movement in the sagittal plane. This is what would be expected because as the subject comes down onto the step she immediately begins moving back up so the total movement is close to zero.

In the frontal plane, the turn step demonstrated the largest amount of center of gravity displacement, whereas the basic and hop steps showed almost none. Because the turn step is the only step that moves in the frontal plane, this result was expected. The performer moves laterally across the step, whereas in the other two steps she moved forward and backward in the sagittal plane. Center of gravity displacement in both planes was found to be greater for the turn step than for either the basic or the hop. This supports the hypothesis which stated that center of gravity displacement would be greater for the turn step than for either the basic or the hop step. Another hypothesis claimed that the basic step would produce a greater center of gravity displacement than the hop step. This was found to be true in the sagittal plane, but in the frontal plane the means for the two steps were the same.

Electromyography of Three Knee Extensors

Vastus Lateralis

The vastus lateralis is involved in knee extension as well as lateral tracking of the knee. It works together with the rectus femoris and the vastus medialis to perform knee extension. Much research has been done to determine if these three muscles work together or separately in knee extension. Most of the researchers agreed that these three muscles work together and that their only separate function deals with patellar tracking (Grabiner, Koh, & Draganich, 1994; Leib & Perry, 1971; Worrell, Connelly, & Hilvert, 1995).

Area under the curve for the vastus lateralis showed that the two step heights were significant for the basic, hop, and turn steps. The basic and turn steps produced significantly greater EMG responses for the 8-in. step height than for the 6-in. step height. For the basic and turn steps more muscle action was involved at the higher step height to create the work needed to raise the center of gravity a greater vertical distance. Also, the lead leg would assist in pulling the body's weight forward and assist in rotating the opposite leg up onto the step. Not only were the EMG areas greater for the 8-in. step compared to the 6-in. step, but significantly greater peak EMG values were found for the 8-in. step compared to the 6-in. step for both the basic and turns steps. The greater peak EMG values would contribute to greater

EMG areas. The opposite was true for the hop step; a greater area was produced for the 6-in. than for the 8-in. step but no differences were found between the peak EMG values for the hop step at 6-in. or the 8-in. step heights. Because the hop step motion moves the pelvic girdle and lower extremities as a single unit in the upward motion of the step, there is little or no need for lateral motion. The greater area that existed for the 6-in. step compared to the 8-in. step could have been caused by the body's motion as a projectile prior to contact with the step. If the height of the center of gravity was approximately the same for both the 6-in. and 8-in. steps, the center of gravity would have fallen a greater distance before contact with the 6-in. step than for the 8-in. step. To deal with the greater impact associated with the 6-in. step, the subject could have spent more time at landing, thus reducing the peak EMG and increasing the time and in turn increasing the EMG area.

Significant differences existed among the EMG areas for the steps at both the 6-in. and the 8-in. steps. At both step heights, all pairwise comparisons were significant. At the 6-in. step height, the hop step produced the largest EMG area response and the basic step produced the smallest EMG area response. This would be expected because the hop is a projectile before landing on the step. Also, it is reasonable to assume that little change would be seen in the EMG area when comparing the 6-in. step to the 8-in. step. The pattern for the basic step and the turn step would be similar with the turn step producing a greater EMG area. The turn step, being a more complex movement with respect to time of execution and motions involved in the movement, would generate large EMG areas. The higher step height, the greater the response of the vastus laterlis to pull the body up and at the same time turn the body 90°. The time to peak EMG results for the vastus lateralis were not found to be significant for any of the variables.

Rectus Femoris

The rectus femoris, which is a two-joint muscle crossing both the hip joint and the knee joint, is involved in knee extension. The EMG readings for area under the curve for the rectus femoris showed very similar results to the vastus lateralis, which would be expected if all of the knee extensors are working together. Height was found to be significantly different across all of the steps with the 8-in. step height having the greatest muscle activity for the basic and the turn steps and the 6-in. step height having the least. The hop step again showed the opposite; the 6-in. step generated greater muscle activity. Examining the steps at each step height it was found that all of the steps were significantly different from one another at the 6-in. step height with the hop step producing the greatest area under the curve and the basic step the least. This was also found for the vastus lateralis. The same pattern existed for the 8-in. step; this was opposite for the vastus lateralis. The significant interaction effect occurred because the basic step and the turn step increased across the steps, 6-in. step to 8-in. step while the hop decreased across the step heights. This could be caused by the greater hip flexion evident in a hop compared to the basic or turn steps and a greater degree of hip flexion needed to jump to a higher height.

The rectus femoris also differed from the vastus lateralis in that there was a significant difference between heights at the 126 bpm cadence, yet there was no significant difference at the 132 bpm cadence. Another significant effect was found between the 126 bpm and 132 bpm cadence at the 6-in. step height. At the 6-in. step height the 132 bpm cadence required greater EMG activity than at the 126 bpm cadence; however, almost the exact same EMG activity was seen at the 8 in. step for the two cadences. Peak EMG for the rectus femoris also showed a significant difference between cadences with the 132 bpm cadence requiring greater EMG activity than the 126 bpm cadence. This would be expected because the rectus femoris is performing the same movement, but it must perform it faster which would require a greater EMG response. Time to peak muscle recruitment was not found to be significant for any of the variables for the rectus femoris.

Vastus Medialis

The vastus medialis is involved in knee extension as well as medial patella tracking. Whether the vastus medialis and the vastus lateralis are both activated together or separately has often been debated. Grabiner et al. (1994) reviewed many studies and reported that the debate could not be solved with current literature because of various methods of data collection and analysis. They claimed that the studies that were most conclusive went against selective vastus medialis activation. If this is correct, then it would be expected that the vastus medialis would show similar EMG activity to the rectus femoris and vastus lateralis responses. This, however, was not the case for this subject. Significant differences were found for time to peak recruitment which was not seen in either of the other two muscles. The significant differences for the area under the curve for the vastus medialis did not resemble the significant differences for the vastus lateralis or the rectus femoris. Dr. Robert Moss (personal communication, February 10, 1998) was consulted and examined the subject's legs and concluded that she had externally rotated tibias. This, he said, would cause her vastus medialis to have to work harder to stabilize the patella and therefore fatigue sooner than the other two muscles. Because the subject was tested in a fatigued state, it is possible that the vastus medialis was already fatigued to the point that it was no longer functioning consistently.

Time to peak muscle recruitment showed a significant difference at the hop step between the 6- and 8-in. step heights. The 8-in. step height took considerably longer time to reach peak muscle recruitment than the 6-in. step height. It would make sense that the 8-in. step height would take longer except that it was not significant for either of the other muscles. The basic and turn steps did not show a significant difference between the 6- and 8-in. step heights. At the 8-in. step height, there was a significant difference between the basic and hop steps as well as the turn and hop steps. The hop step took a considerably longer time for peak muscle recruitment when compared with the other steps. At the 6-in. step height, no significant difference was found. These inconstancies are probably due to the fatigued state of the muscle.

Area under the curve showed significant differences between the step heights at the 132 bpm cadence. This was also seen for the rectus femoris but at the 126 bpm cadence. The cadences were found to be significantly different at the 8-in. step for the rectus femoris but at the 6-in. step height. The hop step was found to be significantly different than the basic and the turn step at the 126 and 132 bpm cadences. These results indicated that at greater step heights, faster cadences, and harder steps the vastus medialis was not consistent because significant differences were found for each of these variables.

Results for the vastus medialis indicated that the hop step showed the greatest differences in muscle recruitment and time to peak recruitment. This same pattern appeared in peak EMG, time to peak, and area under the curve for the hop step; the hop step was significantly different than the other steps, across step heights, and cadences. This indicated that as the vastus medialis fatigues propulsion steps such as the hop step were more variable. This agreed with Spencer and Bartlett (1993), who found that as the subjects fatigued, they could no longer control the load that was applied for the more complex actions like the lunge step. They suggested that only nonplyometric steps should be used towards the end of a step aerobics class due to this fatigue factor.

Summary

The EMG data support the hypothesis that at the 8-in. step height the EMG response would be greater than at the 6-in. step height. This was found to be true across each of the steps for the vastus lateralis and rectus femoris. The only anomaly that existed was that the means of the hop step showed a greater EMG response for the 6-in. step height than the 8-in. step height for the vastus lateralis. If the subject jumped the same height for each step height, then it would make sense that the 6-in. step height would involve a greater EMG response because the subject would have fallen further and required greater muscular activity to slow the body down.

The EMG response was greater at the 132 bpm cadence than the 126 bpm cadence for both the rectus femoris and the vastus medialis. The EMG response for the two cadences was almost identical for the vastus lateralis. This supports the hypothesis that the EMG response at the 132 bpm cadence would be greater than the 126 bpm cadence.

The hop step produced the greatest EMG response for the rectus femoris and vastus medialis. The hop step produced greater EMG responses for the vastus lateralis at the 6-in. step height, but for the 8-in. step height the turn step produced the greatest EMG response. This goes against the hypothesis that suggested that the hop step produces the greatest EMG response when compared to the basic or turn steps.

The data supported the hypothesis that suggested that the basic and turn steps would produce different EMG responses. This was found to be true for all three muscles with the turn step having a greater area under the curve than the basic step for each muscle.

CHAPTER V

SUMMARY, FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The problem of the study was to determine the effects of step height, cadence, and choreography on ground reaction forces, electromyography of the knee extensors, and center of gravity displacement in step aerobics for a single subject in a fatigued state. The subject was involved in 12 experimental conditions which included three step combinations, performed at two different step heights, with two different cadences. The three step combinations were a basic alternating step, a turn step, and a hop step. Each step combination was performed three times, and the subject performed 5 trials for each condition. All conditions were performed in a fatigued state. The study took place in the Exercise Physiology and Biomechanics Laboratory at Western Michigan University. Data were obtained from two force platforms, EMG and two-dimensional cinematographic analyses. Data from the force platforms, EMG, and cinematography were all synchronized. The step heights tested were 6- and 8-in. The muscles measured were the rectus femoris, vastus lateralis, and vastus medialis. The music cadences were 126 bpm and 132 bpm. A completely randomized block design was used to analyze the results. ANOVAs were run on all of the variables and simple main effects and simple simple main effect tests were run when the ANOVA had significant first- or second-order interaction effects. Tukey

HSD tests were run when three or more means were significant. The level of significance was set at .05 for all tests.

Findings

The significant findings of the study were as follows:

1. For vertical impact, a second-order interaction effect cadence by height by step was found, $F(2, 44) = 5.30$, $p < .05$. For the 6-in. step height at 126 bpm, the hop step was greater than the basic step, and the turn step was greater than the basic step. For the 8-in. step height at 132 bpm, the hop step was greater than the basic step, and the hop step was greater than the turn step.

2. For lateral force, a significant difference was found among the steps, $F(2, 44) = 11.97$, $p < .05$. The hop step was greater than the turn step, and the hop step was greater than the basic step.

3. For time to vertical impact, a first-order interaction effect height by step was found, $F(2,44) = 16.97$, $p < .05$. For the basic step, the 6-in. step was longer than the 8-in. step. For the turn step, the 6-in. step was longer than the 8-in. step.

4. For center of gravity displacement in the sagittal plane, a significant difference was found between the cadences, $F(1, 44) = 11.57$, $p < .05$. The 126 bpm cadence had a greater center of gravity displacement than the 132 bpm cadence.

5. For the sagittal plane center of gravity displacement, a significant difference was found between step heights, $F(1, 44) = 13.01$, $p < .05$, with the 6-in. step showing the greater center of gravity displacement than the 8-in. step height.

6. For the sagittal plane center of gravity displacement, a significant difference existed among the steps, $F(2, 44) = 2.44,36$, $p < .05$. The basic step had a

greater displacement than the hop step, and the turn step had a greater displacement than the hop step.

7. For the frontal plane center of gravity displacement, a significant difference was found among the steps, $F(2, 44) = 174.00$, $p < .05$. The turn step was greater than the hop step, and the turn step was greater than the basic step.

8. For the area under the curve for the vastus lateralis, a significant difference was found between the 6- and 8-in. step heights at the basic step, $F(1, 44) = 71.65$, $p < .05$.

9. For the area under the curve for the vastus lateralis, a significant difference was found between the 6- and 8-in. step heights for the hop step, $F(1, 44) = 21.66$, $p < .05$.

10. For the area under the curve for the vastus lateralis, a significant difference was found between the 6- and 8-in. step heights for the turn step, $F(1, 44) = 82.17$, $p < .05$.

11. For the area under the curve for the vastus lateralis, a significant difference was found among the steps for the 6-in. step height, $F(1, 44) = 308.04$, $p < .05$, as well as for the 8-in. step height, $F(2, 44) = 54.46$, $p < .05$.

12. For the area under the curve for the rectus femoris, a significant difference was found between the 6- and 8-in. step heights for the basic step, $F(1, 44) = 38.42$, $p < .05$, with the 8-in. step height producing a greater EMG response than the 6-in. step height.

13. For the area under the curve for the rectus femoris, a significant difference was found between step heights for the hop step, $F(1, 44) = 44.88$, $p < .05$, with the 8-in. step height producing a greater EMG response than the 6-in. step height.

14. For the area under the curve for the rectus femoris, a significant difference was found between step heights for the turn step, $F(1, 44) = 41.09$, $p < .05$, with the 8-in. step producing a greater EMG response than for the 6-in. step height.

15. For the area under the curve for the rectus femoris, a significant difference was found among the steps for the 6-in. step height, $F(2, 44) = 408.83$, $p < .05$, as well as for the 8-in. step height, $F(2, 44) = 94.22$, $p < .05$,

16. No significant difference was found for the first-order interaction effect height by step, $F(2,44) = 2.75$, $p > .05$.

17. For the area under the curve for the vastus medialis, a significant first-order interaction cadence by step was found, $F(2,44) = 6.28$, $p < .05$, for the 126 bpm cadence: (a) the hop step was greater than the basic step, and (b) the hop step was greater than the turn step. For the 132 bpm cadence: (a) the hop step was greater than the basic step, and (b) the hop step was greater than the turn step.

Conclusions

These findings led the investigator to conclude the following:

1. The 6-in. step height produced greater vertical ground reaction forces than the 8-in. step height when the subject made contact with the top of the step.

2. At the 132 bpm cadence, the subject did not move through her full range of motion for the basic, hop, or turn steps.

3. At the 8-in. step height, the subject did not move through her full range of motion for the basic, hop, or turn step.

4. The 8-in. step height required a greater EMG response for the three muscles studied than the 6-in. step height for each of the steps.

5. With the subject in a fatigued state, the higher heights, faster cadences, and more complex steps were not as consistent as the lower heights, slower cadences, and easier steps.

Recommendations

The following are recommendations for further research:

1. Another study should examine a larger group of subjects to determine if these findings would hold true across a greater number of people.

2. Kinematic variables that describe the motion of the step patterns need to be researched in conjunction with ground reaction forces and EMG data.

3. All experience levels of aerobic participants need to be compared to trained aerobics instructor.

4. Other aerobic steps and step heights need to be compared using data collection procedures similar to this investigation.

5. Ground reaction forces should be compared for stepping up and for stepping down.

6. Subjects with known orthopedic complications associated with step aerobics should be studied and compared.

Appendix A

Consent Form

Western Michigan University
Department of Health Physical Education and Recreation
Principal Investigator: Dr. Mary Dawson
Research Associate: Stacie Moore

I have been invited to participate in a research project entitled "The effects of step height, cadence, and choreography on four biomechanical factors in step aerobics." I understand that this research is intended to examine if the higher intensity form of step aerobics is still a low impact activity that is safe for the general population. I further understand that this project is Stacie Moore's thesis project.

My consent to participate in this project indicates that I will be asked to attend one, two hour session with Stacie Moore. I will be asked to meet with Stacie Moore at the Biomechanics Lab at Western Michigan University. I will provide general information about myself such as my age, height, and weight.

I understand that I will be asked to perform step aerobics at a 6 and 8 in. step height, at a 126 bpm and 132 bpm cadence, as well as three different step combinations. The step combinations included the basic step, hop step, and turn step. I understand that each of the 5 trials for each condition will be video taped and that EMG and force platform data will also be collected. For the EMG data electrodes will be placed over 3 of my muscles, rectus femoris, vastul lateralis, and vastus medialis. The site of the electrode placement will have to be scrubbed vigorously with a sterile alcohol pad and the site may need to be shaved to provide better electrode contact surface.

As in all research, there may be unforeseen risks to the participant. If an accidental injury occurs, appropriate emergency measures will be taken; however, no compensation or treatment will be made available to me except as otherwise specified in this consent form. The risks to the research participant in this study include general risks associated with step aerobics such as muscle soreness, muscle strains, and sore joints.

I understand that the current testing may be of no benefit to me. The results of this study may provide aerobics instructors and participants with further knowledge concerning safety when increasing the intensity of aerobics classes.

I understand that all the information collected from me is confidential. That means that my name will not appear on any papers on which this information is recorded. Once the data are collected and analyzed, any paper with my name on it will be destroyed. All other forms including the tapes used for digitizing will be retained for 3 years in a locked file in the principal investigator's laboratory.

I understand that I may refuse to participate or quit at any time during the study without prejudice or penalty. If I have any questions or concerns about this study, I may contact either Dr. Mary Dawson at (616) 387-2720 or Stacie Moore at (616) 372-7142. I may also contact the Chair of Human Subjects Review Board at (616) 387-8293 or the Vice President for Research at (616) 387-8298 with any concerns that I have. My signature below indicates that I understand the purpose and requirements of the study and that I agree to participate.

______________________________ ____________________

Signature Date

Appendix B

Human Subjects Institutional Review Board Approval

Human Subjects Institutional Review Board

Kalamazoo, Michigan 49008-3899

WESTERN MICHIGAN UNIVERSITY

Date: 13 October 1997

To: Mary Dawson, Principal Investigator
Stacie Moore, Student Investigator

From: Richard Wright, Chair Richard A. Wright

Re: HSIRB Project Number 97-09-13

This letter will serve as confirmation that your research project entitled "The Effects of Step Height, Cadence, and Choreography on Four Biomechanical Factors in Step Aerobics" has been **approved** under the **expedited** category of review by the Human Subjects Institutional Review Board. The conditions and duration of this approval are specified in the Policies of Western Michigan University. You may now begin to implement the research as described in the application.

Please note that you may **only** conduct this research exactly in the form it was approved. You must seek specific board approval for any changes in this project. You must also seek reapproval if the project extends beyond the termination date noted below. In addition if there are any unanticipated adverse reactions or unanticipated events associated with the conduct of this research, you should immediately suspend the project and contact the Chair of the HSIRB for consultation.

The Board wishes you success in the pursuit of your research goals.

Approval Termination: 13 October 1998

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