

THE EFFECTS OF BENCH HEIGHT AND STEP
CADENCE IN AEROBIC STEP DANCE
ON FORCE IMPACT AND
METABOLIC COST

by

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ABSTRACT

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Bench step aerobic (BSA) exercise has been shown to help individuals meet the ACSM recommendations for physical activity through the improvement of cardiovascular fitness, body composition, and aerobic capacity in a wide variety of populations. The purpose of this present investigation was threefold: to (1) determine the acute metabolic and cardiorespiratory responses of simple bench step aerobics at two cadences (128 and 134 beats·min⁻¹) and two bench heights (6 and 10 inches), (2) calculate the average vertical ground reaction force (VGRF) and time to peak (TPEAK)

at these cadences and bench heights, and (3) attempt to create a regression equation to predict force impact and caloric cost for a given individual based upon physiological height, weight, step cadence, and bench height using the resultant ground reaction forces and metabolic costs. Twelve subjects reported to the exercise physiology lab three times: (1) prescreening and maximum treadmill testing, (2) two of the four conditions, and (3) the remaining two conditions. Forty-eight hours rest was allowed after the maximal treadmill test and at least twenty-four hours rest between each lab visit before subjecting individuals to the various experimental conditions. At least fifteen minutes was allotted between exercise conditions within each lab visit. The effect of stepping cadences and bench heights on the averages of HR, VO_2 , RER, caloric expenditure ($\text{kcal}\cdot\text{min}^{-1}$), VGRF, and TPEAK were determined using four separate 2 x 2 analysis of variance (ANOVA) with repeated measures. There were significant differences between bench height and cadence with all the dependent variables (TPEAK, KCAL, and VGRF). No significant interactions were reported between the independent variables (bench height and cadence) for any variable. A regression analysis using step cadence, bench height, subject height and subject weight to predict force impact and metabolic cost yielded modestly reliable equations. In conclusion, bench step aerobics is an effective low-intensity exercise. Definitive intensity modifications may be made through both the cadence of the music and the height of the participant's bench. However, additional research is necessary to determine each individual's threshold for beneficial training adaptations and increased injury risk.

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CHAPTER 1

INTRODUCTION

With a growing majority of Americans overweight, inactive, and at risk for serious health complications, the American College of Sports Medicine (ACSM) published exercise recommendations in 1998 for improving cardiorespiratory endurance, controlling body weight, and reducing the risk of premature chronic disease. The recommendations assert that an individual should perform 20 to 60 minutes of continuous or intermittent aerobic exercise at an intensity between 55% and 90% of maximal heart rate 3 to 5 days per week. ACSM also suggests that individuals should achieve approximately 300 kcal of energy expenditure per day in physical activity or exercise for optimal health and fitness improvements and weight control (2). Bench step aerobic (BSA) exercise has been shown to help individuals meet the ACSM recommendations for physical activity through the improvement of cardiovascular fitness, body composition, and aerobic capacity in a wide variety of populations including patients with heart failure (19,28,29,31,32). Since the late 1980's, this exercise format has become a widely practiced fitness modality, especially among the female population (28).

The popularity of this exercise format is due in part to the growing emphasis on low-impact activities after a high rate of injuries were reported for high-impact aerobic

dance (10,16,17,28). BSA is claimed to be a high-intensity low-impact alternative to high-impact aerobic dance with less risk of injury; even so, many researchers now believe that this form of exercise is not as low-impact an activity as originally thought. Modeled after the aerobic dance group exercise format, stylized movements are performed to popular music using an adjustable platform and led by a certified group exercise instructor. The cadence of the stepping rate is largely determined by the instructor and bench height is usually selected by the participant; However, the Aerobics and Fitness Association of America (AFAA) recommends a range of 118 to 126 beats per minute ($\text{beats}\cdot\text{min}^{-1}$) on a bench ranging in height from 6 to 8 inches in order to reduce the risk from injury (1). Nevertheless, a survey of group exercise BSA instructors in April, 2000, suggested that a large portion of instructors are disregarding these safety guidelines and teaching BSA classes at cadences of 125 to 133 $\text{beats}\cdot\text{min}^{-1}$ (34). The mechanism for most injuries among BSA participants is commonly purported to be related to the degree of vertical ground reaction forces (VGRF) which can vary significantly with stepping rate (30).

Claiming an even more noteworthy role in the degree of VGRF experienced by BSA participants is bench height. Maybury and Waterfield (1997) found significant differences in peak force at foot contact between benches 6 and 10 inches high, but not between 8 and 10 inch benches (21). Although VGRF values tend to increase with increasing bench height, one study found that bench height must differ by at least 4 inches before a significant difference in VGRF is measured (24). Nevertheless, these

measured ground reaction forces for BSA have been compared to those experienced by participants engaging in several popular aerobic exercise activities such as jogging and aerobic dance and were discovered to be significantly lower. Based on these data, it was concluded that BSA is still a relatively low-impact form of exercise with significant aerobic benefits (18).

In the midst of all the focus surrounding VGRF, BSA exercise, and potential injury, there still exists an undisputed profound cardiorespiratory and metabolic effect with this popular exercise format. Current data have shown a direct relationship among stepping cadence, bench height, and oxygen consumption (13-15,19,20,31,32). Furthermore, the addition of light hand weights or plyometric movements can increase the metabolic response significantly (13,14,19,20). Therefore, participants are often advised by group-exercise instructors to increase step height or add hand weights or plyometric movements to increase the caloric cost of the exercise session without consideration to the participant's height and weight or other potential limitations. No studies to date have sought to combine these variables with stepping cadence and bench height in order to create a regression equation to predict force impact. This model may be useful in determining a more appropriate cadence and bench height recommendation to reduce the risk of injury yet maximize the physiological benefits.

1.1 Purpose

The purpose of this investigation was threefold: (1) determine the acute metabolic and cardiorespiratory responses of simple bench step aerobics at two

cadences (128 and 134 beats·min⁻¹) and two bench heights (6 and 10 inches), (2) calculate the average VGRF and time to peak (TPEAK) at these cadences and bench heights, and (3) attempt to create a regression equation to predict force impact and caloric cost for a given individual based upon physiological height, weight, step cadence, and bench height using the resultant ground reaction forces and metabolic costs.

1.2 Hypothesis

There exists a point of diminishing returns for each individual beyond which the metabolic gains are minimal while the injury risk determined by the increased VGRF is much greater. This level may be strongly influenced by an individual's height and weight, but is most certainly determined by a particular combination of step cadences and bench heights.

1.3 Definition of Terms

Absolute and relative maximal oxygen consumption (VO_{2max}): VO_{2max} is expressed as an absolute, or relative value. Absolute VO_{2max} is simply the maximal oxygen uptake expressed in liters per minute. Absolute fitness is important in activities where body weight is not lifted such as in cycling, swimming and handling of objects and weights, other than body weight. Relative VO_{2max} is absolute VO_{2max} divided by body weight and it is expressed in milliliters of oxygen per body weight (kg) per minute (ml/kg/min). Relative VO_{2max} is important in activities where body weight is lifted such as in walking, running and climbing uphill. In adults, relative VO_{2max} is more important than

absolute VO_{2max} as a health indicator.

Bench Step Aerobics (BSA): innovated by Gin Miller around 1989, it is distinguished from other forms of aerobic exercise by its use of an elevated platform (the step), which enables a more vigorous workout than can be achieved with "regular" aerobics. One form of step is called tap-free or smooth step in which feet always alternate without the ambiguous "taps" that can make learning step difficult for beginners. Often moves are referred to as Reebok step moves in reference to one of the first makers of the plastic step commonly used in gyms.

Cadence (b/min): the measure or beat of movement, as in dancing

Exercise: planned, structured, and repetitive physical activity done to improve or maintain one or more components of physical fitness.

Kilocalorie (kcal): term used to represent the amount of energy required to raise the temperature of a liter of water one degree centigrade at sea level. In nutrition terms, the word calorie is commonly used to refer to a unit of food energy. Technically, however, this common usage of the word calorie of food energy is understood to refer to a kilocalorie.

Maximal Oxygen Uptake (VO_{2max}): the product of the maximal cardiac output (L blood/minute) and arterial-venous oxygen difference (ml O_2 /L blood). It is accepted as the criterion measure of cardiorespiratory fitness and is closely related to the functional capacity of the heart.

Physical activity: bodily movement that is produced by the contraction of skeletal muscle and that substantially increases energy expenditure.

Respiratory Exchange Ratio (RER): the ratio of the net output of carbon dioxide to the simultaneous net uptake of oxygen. Utilized as a measure of exercise intensity, it can be used to determine total energy expenditure and specific substrate utilization during physical activity.

Vertical Ground Reaction Force (VGRF): Ground reaction force is a concept that is used to describe the reaction force provided by the supporting horizontal surface. It is derived from Newton's law of action-reaction to represent the reaction of the ground to the acceleration of all the body segments.

1.4 Delimitations

The twelve subjects in this study were comprised of females between the ages of 18 and 45 years. They were required to have at least two weeks participation experience with step aerobics and possess a BMI value less than 30. Subjects must report to the lab in a fasted state (at least 3 hours after food ingestion) with no caffeine consumption within 8 hours for each testing session. Oxygen uptake, respiratory values, and heart rate were measured with a metabolic cart. Data collection was completed in a two-week period with at least 24 hours between each testing session. Order of treatment was determined using a balanced Latin square. Subjects were required to exercise on the bench for a minimum of 5 minutes and achieve a 3-minute steady state

before resting. Subjects must step completely on the force plate for each impact measurement.

1.5 Assumptions

The Zuntz table accurately predicts caloric expenditure using the respiratory exchange ratio in conjunction with VO_2 (L/min). The RER value is a true representation of exercise intensity. Twelve subjects is a genuine representation of a larger population. Two weeks of bench step aerobic training is sufficient to assume proficiency. A maximal treadmill test is a true representation of maximal VO_2 . Waiting three hours after eating is a sufficient amount of time to ensure a fasted RER value.

1.6 Limitations

Subjects moved their arms freely, which may serve to falsely elevate heart rate. The movements on the bench were chosen for the ease with which data may be extrapolated. They were not truly representative of an actual bench step aerobic class. Only females between the ages of 18 and 45 were used, thereby limiting the applicability of the data. Some subjects may not have provided a true report with regards to the guidelines for food, beverage, and caffeine consumption prior to each testing session.

CHAPTER 2
REVIEW OF LITERATURE

2.1 Aerobic Dance

In 1968, American physician Kenneth Cooper coined the term “aerobics” in his exercise book *Aerobics*. He used the term to describe exercises that use oxygen to keep large muscle groups moving continuously for at least 20 minutes. Based on this definition, the name “aerobics” came to refer to calisthenics taught to music (11). Americans Judi Sheppard Missett and Jacki Sorensen were two early aerobics pioneers. They produced early forms of dance-based routines that became the basis of group fitness classes. The term “aerobic dance” (AD) was created and became very popular with female audiences (11).

Traditional AD consists of a series of multi-directional movements set or “choreographed” to the rhythm of music. Since its inception, researchers sought to establish its training effect on the cardiorespiratory and muscular systems (6,9). These investigators found overwhelming evidence that AD provided a significant cardiovascular stimulus for aerobic conditioning. The early performances of these routines involved suspension phases of the body during which both feet were momentarily off the floor. The hazardous nature of this high-impact form of exercise

was rapidly recognized and modifications began to appear in an attempt to reduce AD injuries while maintaining an adequate intensity for aerobic conditioning. The resultant lower-impact version of this popular fitness format was characterized by one foot remaining in contact with the floor at all times, effectively eliminating the suspension phase of the activity. With these key changes in its choreography, investigators were uncertain whether a similar cardiorespiratory training stimulus remained. In 1989, McCord, Nichols, and Patterson sought to establish the effect of low-impact dance training on aerobic capacity, submaximal heart rates, and body composition of college-aged females. Sixteen females volunteered for this twelve-week study. The subjects exercised three times per week for 45 minutes each session at 75-85% of their heart rate reserve. Upon completion of the exercise protocol, posttest results revealed a small but significant increase in VO_{2max} and significant decreases in both submaximal heart rates and body fat. It was concluded that low-impact AD was as effective as other endurance training regimens in improving cardiovascular fitness and body composition (22).

2.1.1 Relationship between Heart Rate and Oxygen Consumption

That same year, Williford et al. determined that AD must be performed at high intensity levels in order to meet the minimum guidelines recommended by the American College of Sports Medicine in 1986 (35). This finding prompted researchers to investigate alternative methods for varying exercise intensity while maintaining the low impact benefits of aerobic dance. In 1991, Carroll, Otto, and Wygand examined the metabolic cost of two ranges of arm position height with and without hand weights

during low-impact AD. Ten volunteers performed identical routines with arm movements both above and below shoulder level, with and without hand weights. Neither the use of hand weights nor the change in arm position significantly altered the energy cost of the exercise; however, a significant heart rate response was recorded and researchers cautioned the use of heart rate as an indicator of intensity in low-impact AD (5).

Several years after this finding, Bell and Bassey in 1994 explored the relationship between heart rate and oxygen uptake in both low-impact and high-impact AD (3). The data revealed that the addition of arm work significantly increased heart rates without concurrent increases in oxygen uptake. In addition, Bell and Bassey discovered that the higher heart rates during the high-impact exercise achieved unsafe levels - a genuine concern for less-fit participants (3). This conclusion was confirmed one year later by Darby et al (7). With a more complex protocol that varied impact, cadence, and arm movement, Darby et al. measured the physiological responses of 16 volunteers to various AD routines. A significant Impact x Step interaction was discovered whereby oxygen consumption was greater for the high impact-less arm movement activity, while the low impact-more arm movement activity was greater for heart rate. These increased heart rate responses prompted the investigators to encourage sedentary individuals to use caution when considering participation in some choreographed activities (7).

2.1.2 Additional Physiological Responses

With the rapidly accumulating research concerning AD, the unanticipated heart rate data attracted the attention of a group of researchers. In 1997, De Angelis et al. presented the predicament in measuring intensity when combinations of high- and low-impact activities were included in one AD session. With the very nature of the activity defined by its name – “aerobic” – it was proposed that there was, in fact, a potential element of anaerobic activity to AD. With the failure of heart rate to determine intensity in previous studies, De Angelis determined to measure blood lactate as a further indicator of exercise intensity. Thirty female volunteers were monitored for heart rate and blood lactate responses during a typical 50-minute aerobic dance session consisting of a combination of both low- and high-impact movements. The data revealed a significant anaerobic energy contribution during the combined impact portion of the exercise session, leading the researchers to concur with Bell and Bassey regarding the participation of sedentary individuals. Pre-participation medical screening was encouraged before beginning an AD exercise program (3,8).

2.1.3 Impact Forces and Injury

With the increasing versatility of AD as an effective form of exercise, people of all ages participate for a variety of reasons such as cardiovascular fitness, improved muscle tone, and stress reduction. Previous studies have proven the significance of this exercise format for aerobic conditioning and body composition. However, not all of the

results of this form of exercise are beneficial. Weight-bearing activities have been found to commonly produce overuse injuries, and AD is no exception. In the 1980's, researchers began compiling data regarding AD injuries among both the instructors and its participants. Rothenberger et al. published a study in 1988 cataloguing the prevalence, types, and predisposing factors of injuries experienced by 726 aerobic dancers. The data revealed that 49% of the subjects reported a history of at least one injury related to AD. Most of the injuries were to the shin (24.5%), lower back (12.9%), and ankle (12.2%). The frequency with which subjects exercised was associated with a history of injury. At greater than four AD exercise sessions per week, the injury percentage increased from 43% to 66% when compared to subjects who exercised three times or less per week. The authors proposed a "critical" point of dancing beyond three times per week that placed subjects at risk of injury (28). These injury statistics for AD are not unlike those reported in 2001 by Garrick and Lewis for professional ballet dancers and du Toit and Smith for AD instructors who found the majority of injuries occurring in the lower extremities (10,12).

On the heels of the Rothenberger investigation, Dr. Charles R. Belt published an article in 1990 in the *American Family Physician* corroborating the findings of Rothenberger et al. He stated, "The injuries associated with aerobic dance can generally be classified as overuse injuries, resulting from repetitive force applied to a structure to an extent that exceeds the structure's ability to withstand it...most injuries are of the overuse type and most are in the legs." He suggested a decrease in the

frequency of AD participation or an increase in alternative forms of aerobic exercise such as low-impact aerobics or water aerobics (4). This same year, Janis concluded that AD instructors incurred the highest rate of injury (53%) when compared to participants in both high-impact AD (35%) and low-impact AD (24%) when analyzed in terms of age, number of workouts, shoe type, and floor type (17).

In response to these findings, Reeves et al. conducted a study in 1992 measuring the actual biomechanical responses to high-impact versus low-impact AD. The data revealed a significant difference among mode of AD with vertical forces greater for high-impact than those observed for low-impact. Interestingly, statistical analysis revealed no significant differences among the metabolic requirements for high- versus low-impact AD. It was concluded that both modes of AD produced sufficient metabolic demands on the aerobic capacity of individuals; however, AD participants that engage in low-impact AD may reduce their susceptibility to developing overuse injuries due to the lower loading rates and passive forces associated with it (25).

One year later, Michaud et al. published a study comparing the ground reaction forces generated during low- and high-impact AD using AD instructors as subjects. Analyzing both the vertical and lateral components of the ground reaction forces, the authors discovered a higher vertical peak force in the high-impact AD, but the lateral forces between the two modes were comparable. They reasoned that the maximum vertical peak force produced during high-impact AD was comparable to that generated during intense running and was most likely contributory to the development of overuse

injuries. With respect to the similar lateral forces measured, the authors concluded that the soft tissues of the ankle and knee susceptible to lateral shear forces may be compromised in both modes of AD. Unlike previous studies, the authors reported a time to peak of less than 50 ms following initial contact. Since a reaction time of 50 ms is needed for the neuromuscular system to respond to a force, forces applied during this time may not be effectively dissipated by the musculature (23).

2.2 Bench Step Aerobics

Since the origin of aerobic dance in 1969, different forms of this exercise format have been introduced in order to maintain the motivation and attention of its participants. Increasing needs for program diversity launched formats such as water aerobics, indoor cycling, kickboxing, and bench step aerobics (BSA). Since the late 1980's, BSA has become a widely practiced and popular fitness modality due to the continued emphasis surrounding the benefits of aerobic exercise and the need for more low-impact activities. Bench step aerobics is characterized by a series of choreographed movements to music using an adjustable bench to alter the intensity of the exercise. Both the stepping rate (music cadence) and bench height may be modified to manipulate the intensity of the workout experience. Hand weights and more complex stepping patterns may also be added to increase the aerobic benefit of the exercise.

From its establishment, BSA claimed to be a high-intensity low-impact workout with a relatively low injury risk and was recommended as an alternative to high-impact AD. New or non-traditional exercise formats have often been viewed with skepticism

in terms of providing enough of a physiological stimulus to satisfy accepted exercise criteria. Bench step aerobics is no exception. With its growing popularity, researchers commenced investigations to determine the ability of BSA to effectively improve aerobic capacity, yet remain a low-impact exercise option for the population.

2.2.1 Physiological Responses

A wealth of research was conducted in the 1990's concerning the physiological and metabolic effects of BSA. In 1991, Olson et al. published one of the first studies using continuous choreographed movements on a bench. Four bench heights were employed (6, 8, 10, and 12 inches) while female subjects performed identical 20-minute choreographed routines on each height. Oxygen uptake responses were significantly more pronounced in direct relationship to the bench height, while the addition of 2-pound hand weights elicited a modest but significant increase in VO_2 with the 8-inch bench. The authors concluded that BSA may provide sufficient cardiorespiratory demands for enhancing aerobic fitness in females (29).

Stanforth et al. used this foundational research to fuel their hypothesis in 1993 that leg length, stepping rate, body weight, and fat-free mass would affect the aerobic requirement of BSA in addition to bench height. Twenty-eight females volunteered to march up and down for five minutes on benches at four different heights and two different speeds. The authors removed the confounding factor of arm movement by placing them on the hips during the exercise portion. The data revealed that the aerobic requirement of BSA as measured by the VO_2 response was primarily impacted by bench

height, body weight, and stepping rate. When compared to treadmill exercise, the relationship between the VO_2 and heart rate responses in BSA was similar. (32) That same year, Thomas et al. confirmed the conclusions of Stanforth et al., finding no variation in the oxygen uptake responses to BSA when allowing for age, aerobic fitness, leg length, or adiposity (33).

In accordance with the variations of BSA that were appearing in aerobic dance classes, Greenlaw et al. measured the responses of heart rate and VO_2 to power movements on the bench versus traditional BSA. Eighteen female subjects performed equally-choreographed routines of either low-impact or propulsive step movements on bench heights of 4, 6, or 8 inches. In agreement with previous studies, the authors discovered a greater energy cost with the power format when compared to traditional low-impact BSA (14).

In 1996, Scharff-Olson et al. published a review article discussing the physiological effects of bench/step exercise in response to the numerous investigations exploring this popular exercise format. The authors discovered a consistency among the reported heart rate data and bench height. As bench height increases, heart rate increases, as well. Moreover, the addition of hand weights substantially augments the previously increased heart rate response to BSA. With regards to the acute energy cost of BSA, it was reported that the variables bench height, stepping rate, body weight, and hand weights were the most effective at significantly affecting the energy cost of the activity. Few training studies have been conducted using BSA; however, Scharff-Olson

et al. discovered two studies whose data revealed a 16% and 11% increase in VO_{2max} after 10 and 12 weeks of BSA training, respectively. Differing results concerning changes in body composition were found among studies, while muscular strength and endurance improvements in BSA training studies only occurred in those using hand-held weights (28).

In light of these investigations revealing the many cardiorespiratory benefits of BSA in healthy subjects, Sturm et al. examined the effects of BSA on a diseased population. Twelve weeks of moderate-intensity BSA (50% of VO_{2peak}) was assigned to 26 patients with severe chronic heart failure. At the conclusion of the training period, significant increases in VO_{2peak} , peak workload, and percent of predicted power ability were reported. The authors concluded that BSA was not only effective for this population, but also a safe exercise option in patients with heart failure (32).

As the generated research regarding the various formats and performance options for BSA progressed, group exercise certification organizations began recommending specific stepping rates and bench heights for optimal safety. Precise information about the energy cost of BSA using common stepping rates and bench heights was limited. With the majority of investigations employing little to no arm movement in the exercise protocols, Grier et al. proposed an examination of the acute metabolic and cardiovascular responses of choreographed BSA with combined leg and arm movements at two cadences (125 and 130 $beats \cdot min^{-1}$) and bench heights (6 and 8 inches). Thirty females who were currently participating in BSA classes volunteered

for the study. The subjects completed identical videotaped 8-minute submaximal routines utilizing the various cadences and step heights. The data revealed no significant differences in Rating of Perceived Exertion, heart rate, or VO_2 between the two stepping rates; however, significant differences were observed for the previous variables between the two step heights. The authors cautioned BSA instructors in the use of faster cadences to increase exercise intensity; instead, they encouraged the use of slower stepping rates to minimize the risk of injury for less-experienced participants (15).

The most recent study involving BSA was conducted in 2006 by Rixon, Rehor, and Bemben. They hypothesized that more calories would be expended by activities that involved both upper- and lower-body muscle groups and that most forms of aerobic dance would be as effective as jogging at $8 \text{ km}\cdot\text{hr}^{-1}$. Caloric expenditure was assessed in four popular modes of aerobic dance - resistance aerobics, indoor cycling, BSA, and kickboxing - with the assistance of 28 female subjects. Each exercise format continued for 60 minutes with the exception of indoor cycling (45 minutes) and was led by a certified, experienced instructor. Resistance aerobics recorded the lowest energy cost while no significant differences existed among the other three modes of AD. The data revealed a significant difference between the energy cost of all four modes of AD and that of jogging at 8.05 km/h. Kickboxing, indoor cycling, and BSA were found to have higher energy costs than that of jogging. The authors encouraged participation in kickboxing, indoor cycling, or BSA exercise formats for the purpose of weight

management (26).

2.2.2 Physiological Responses with Added Resistance

One of the earliest studies involving BSA included the use of hand weights. In 1989, Goss et al. evaluated the energy cost associated with combined bench stepping and rhythmic pumping of light hand-held weights. Due to the low-impact nature of BSA, the investigators explored the addition of hand weights as a means to increase the energy cost of the exercise yet still retain its low injury risk characteristics. The bench heights remained constant while the stepping rate and applied resistance varied with each trial. The data presented a small but significant increase in energy cost with the application of rhythmically pumping hand-held weights. This increase was comparable to the energy cost of running at 7 miles per hour for 35 minutes for a 77 kg individual. The authors observed a distinct anaerobic component to the measured R values for portions of the exercise protocols, yet concluded that the rhythmic pumping of light hand-held weights during BSA is as effective as conventional exercise modes in increasing daily energy expenditure (13).

Several years passed before researchers once again evaluated the use of resistance training with BSA. The first investigation of its kind, the resistance component was separate from the BSA exercise and a 12-week training study was created to evaluate the cumulative effects of this combination on comprehensive physiological alterations. Thirty-five female volunteers were divided into four groups by Kraemer et al. in this 2001 study. Two groups were BSA only – 25 and 40 minutes

– while one group combined 25 minutes of BSA with an upper- and lower-body resistance program and one group served as the control. The primary findings of this investigation were: (1) resistance training can augment improvements in aerobic fitness in combination with BSA; (2) the addition of a resistance training component contributes to the development of greater changes in muscular power and strength not attained by BSA alone; and, (3) BSA is capable of enhancing some basic strength and power characteristics of the lower body leg musculature. The authors concluded that the addition of a resistance component in a typical aerobic conditioning program was important for overall physical fitness and may be used in conjunction with the already substantiated benefits of BSA exercise (19).

A more recent study investigating the effects of added resistance to the cardiovascular response during BSA was published by La Torre et al. in 2005. Recognizing the overabundance of studies conducted using hand-held weights, these researchers designed a protocol in which appendicular overload was achieved through various pockets in a jumpsuit. Subjects were fitted with a track suit and loads were placed in pockets close to the legs and arms equivalent to 10% of the subject's body mass. Heart rates were closely monitored and VO_2 was estimated using the individual heart rate- VO_2 relationships determined previously in the lab. The data revealed a significant cardiovascular response to the weighted exercise protocol, consistent with results from previous studies done in a similar manner. In conclusion, the authors reported the observation that some participants experienced exercise intensities above

90% their maximum heart rate during the weighted conditions, and cautioned that some exercise proposed as moderate may be too intense for obese individuals (20).

2.2.3 Impact Forces and Injury

Limited research has been published regarding the biomechanical aspects of BSA and injury rates of the participants. Most investigations focused on the vertical ground reaction forces associated with this exercise format. In a review article published by Scharff-Olson in 1996, two studies investigating impact forces and BSA revealed these reaction forces ranging from 1.4 to 1.7 times the bodyweights of the subjects. In all studies examined by Scharff-Olson, higher bench heights and faster stepping rates elicited greater vertical ground reaction forces with less time to peak. The most significant differences existed between bench heights that differed by at least four inches (28).

The following year, two studies were published investigating the vertical impact forces elicited by increased stepping rates and bench heights during BSA. Scharff-Olson et al. compared the vertical force responses of novice participants to BSA instructors when stepping rates were manipulated. An 8-inch bench was utilized with stepping rates of 30 and 33 cycles·min⁻¹ for the performance of 8-minute protocols with basic and advanced movements. No significant differences were observed between the two groups for peak vertical impact force; however, the instructors generated a shock-absorbing tendency when exiting the bench. The authors concluded this was a result of

experience and served to reduce the injury risk associated with higher impact forces resulting from faster stepping rates in BSA (30).

Augmenting the growing research on impact forces and BSA, Maybury and Waterfield published a pilot study in 1997 reporting the effects of bench height on ground reaction forces. Testing the claim that BSA was a high-intensity low-impact workout that produced ground reaction forces comparable to those of walking, they assigned 12 female volunteers to three exercise sessions with three different bench heights (6, 8, and 10 inches). The results from this investigation supported previous claims that impact forces increased with bench height. However, they did not find a correlation between increased impact force and body weight as expected. The resulting discussion examined the various aspects of potential injury risk with these increased vertical forces on the musculoskeletal system. They determined that several factors such as the moment forces acting about the joints, eccentric muscle activity, fatigue, longitudinal loading, leg length, and aging footwear ultimately contribute to the risk of injury (21). These findings support those of Scharff-Olson et al. in 1996 with regards to injury rate and impact. Nevertheless, when compared with more conventional aerobic activities such as running, BSA maintained a lower percentage of overall injury rates. Only when the frequency of participation in BSA surpassed two hours per session at least four times per week did the data reveal comparable injury rates across activities. Still, the severity of the reported injuries was low, did not require medical intervention, and disappeared within several days (28).

CHAPTER 3

METHODS

3.1 Experimental Design

This study incorporated four separate conditions within the experimental design: (1) two step cadences measured in beats per minute ($\text{beats}\cdot\text{min}^{-1}$) and (2) two bench heights measured in inches (in). For step cadence, two speeds were used (128 and 134 $\text{beats}\cdot\text{min}^{-1}$) to determine its effect on joint force impact and metabolic cost. In conjunction with the stepping speed, bench height was adjusted (six inches and ten inches) to examine its concurrent effect on the previous dependent variables. This study is a 2 x 2 (speed x bench height) repeated-measures design with the independent variables as stepping speed (128 and 134 $\text{beats}\cdot\text{min}^{-1}$) and bench height (6 and 10 in.) and the dependent variables as vertical ground reaction force (VGRF), time to achieve peak force (TPEAK), and caloric expenditure (KCAL).

Treatment orders for step cadence and bench height were counterbalanced using a balanced Latin Square. The subjects reported to the exercise physiology lab three times: (1) prescreening and maximum treadmill testing, (2) two of the four conditions, and (3) the remaining two conditions. Forty-eight hours rest was allowed after the maximal treadmill test and at least twenty-four hours rest between each lab visit before

subjecting individuals to the various experimental conditions. At least fifteen minutes was allotted between exercise conditions within each lab visit.

3.2 Prescreening

Females aged 18 to 45 years were asked to volunteer for this study. A preliminary telephone interview was conducted on each subject to determine if the subject met the prerequisite criteria for at least two weeks of step aerobic dance experience. Subjects who met the participation criteria were asked to present themselves at the Exercise Physiology Laboratory in the Department of Kinesiology for a final exclusionary test using the Body Mass Index (BMI). The subject's BMI was calculated using the equation developed by Lambert Adolphe Jacques Quetelet, body weight in kilograms divided by height in meters squared (kg/m^2). Subjects with a BMI value greater than 30 were then dismissed from the study, while those with a BMI less than 30 continued with the prescreening process. Each subject completed an informed consent and an AHA/ACSM Health/Fitness Pre-participation Screening Questionnaire, and was included in the study with one or no positive risk factors for cardiovascular disease, according to ACSM guidelines. Subjects were excluded from the study if they indicated health risks due to cardiopulmonary, metabolic, or coronary heart disease. This study was approved by the University Institutional Review Board for Human Subject Research.

3.3 Maximal Treadmill Test

Prior to maximal testing, subjects were instructed to avoid caffeine consumption eight hours before or consuming food or beverages other than water for the three hours prior to testing and to refrain from strenuous exercise for 48 hours. The maximal

Table 3.1 Protocol for the maximal treadmill test

Stage (2 min.)	Speed (mph)	Grade (%)	METS
Warm up	2.8	0	1-2
1	3.0	0	3-4
2	3.0	5	5-6
3	3.5	7	7-8
4	3.5	9	9-10
5	4.0	13	11-12
6	4.0	15	13-14
7	4.5	16	15-16

treadmill test was completed on an automated motor-driven Q-stress treadmill, Model TM65 (Quinton, Inc., WA, USA). The treadmill protocol involved a 2-minute warm-up at 3.0 mph and 0.0% grade, followed by 2 minute exercise stages (Blevins, personal communication). Both speed and grade were increased every 2 minutes for an average 2-3 MET intensity increase per stage until the participant could no longer continue (See Table 3.1). These increases elicited an average maximal response of 10-11 METS after approximately 10 minutes. Exercise heart rates were constantly monitored using an electronic monitoring system (Polar, Port Washington, NY). Blood pressures were assessed with a manual sphygmomanometer in the last minute of each stage. Respiratory responses including oxygen uptake (VO_2) and respiratory exchange ratio

(RER) were recorded using a ParvoMedics metabolic cart (True One 2400 Metabolic Measurement System, Utah, USA).

The highest average full-minute oxygen uptake measured during the test was accepted as the VO_{2max} . VO_2 values were considered maximal when two of the following four criteria were met: (a) RER equal to or greater than 1.15; (b) HR no less than 10 beats below the age-predicted HR_{max} ($220-age$); (c) Rating of Perceived Exertion (RPE, Borg, 1982) greater than 17; and (d) a leveling off of VO_2 despite an increase in power output. Upon termination of the maximal exercise test, each subject walked at a self-selected intensity until HR recovered to $120\text{ beats}\cdot\text{min}^{-1}$ or less.

3.4 General Procedures

Following at least 48 hours after completion of the maximal treadmill test, subjects reported to the laboratory and were each assigned a treatment order using a 4 x 4 balanced Latin Square. This design for treatment order attempts to account for a possible learning effect among subjects, thereby reducing the potential for data interference. The four experimental conditions were as follows: (1) step cadence at 128 b/min and bench height at six inches, (2) step cadence at $128\text{ beats}\cdot\text{min}^{-1}$ and bench height at ten inches, (3) step cadence at $134\text{ beats}\cdot\text{min}^{-1}$ and bench height at six inches, and (4) step cadence at $134\text{ beats}\cdot\text{min}^{-1}$ and bench height at ten inches.

3.4.1 Instrumentation and Data Collection

The step aerobic protocol was performed on The Step Aerobic Bench, Model F1005W, dimensions 14 in .x 40 in .x 4 in. (USA). Two-inch risers manufactured

specifically for this bench were used underneath each end to achieve the desired height. A metronome maintained a constant cadence and the ParvoMedic metabolic cart analyzed the expired gases for absolute oxygen consumption (VO_2) and respiratory exchange ratio (RER). Caloric expenditure was then calculated from these individual values using a Zuntz table. Heart rate was measured with a Polar heart rate monitor. Ground reaction forces were measured using an AMTI, Model OR6-7-1000 force platform (AMTI, Watertown, MA).

3.4.2 Experimental Protocol

The step aerobic bench was placed approximately 2 inches in front of the force platform which was imbedded in the floor of the laboratory. The right edge of the bench was flush with the right edge of the force platform in order to appropriately measure the vertical force impact of the right foot only. The metabolic cart was positioned approximately 6 inches in front of the bench. Small adjustments to the bench and metabolic cart placements were made for each individual in order to maximize the subject's comfort level.

The Polar heart rate monitor was strapped onto the subject and the subject was allowed to spend several minutes practicing with the step cadence and bench height being used for that particular treatment condition. The subject was instructed to step up to the bench with one foot and tap the top of the bench with the other foot, then step down, first with the foot that tapped then the other. This movement would be repeated at the other corner of the bench with the opposite lead foot stepping up to the bench

first. The subject was also cautioned that only the right foot may contact the force platform and this contact must be made with the entire foot. In other words, the subject stepped up to the bench with the right foot while facing left and turned at a 45 degree angle. The left foot tapped the top of the bench at the bottom left corner. The subject exited the bench stepping down with the left foot then the right, which stepped directly and completely onto the force platform. This movement was repeated at the bottom right corner of the bench, leading with the left foot. These alternating bench taps were performed at either $128 \text{ beats}\cdot\text{min}^{-1}$ or $134 \text{ beats}\cdot\text{min}^{-1}$ with a metronome and various bench heights of either 6 inches or 10 inches. The subject's foot placement on the force platform was closely monitored in order to make small adjustments to the bench position for optimal data recording. When the subject indicated at least a moderate degree of comfort with the movement speed and bench height, the subject's heart rate was allowed to return to within 10 beats of the resting heart rate and headgear and a mouthpiece were then fitted onto the subject.

The subject was instructed to continue until steady state, as determined by a heart rate varying by no more than $5 \text{ beats}\cdot\text{min}^{-1}$ from the previous heart or VO_2 plateau, was reached. Upon reaching steady state, the subject was encouraged to complete an additional 3 minutes before terminating the test in which all 3 heart rates varied by no more than $5 \text{ beats}\cdot\text{min}^{-1}$. If steady state was not achieved within the minimum 5-minute period, the subject was encouraged to continue until a 3-minute steady state was completed up to a maximum of 8 minutes unless voluntary termination of the test before

this time period was indicated. The subject's RPE was recorded upon completion of the testing condition and the subject was instructed to rest at least 15 minutes or until the heart rate returned to within 10 beats of the resting value before starting the next treatment condition or exiting the lab. A cleaned sterile mouthpiece was used between each testing condition and the metabolic cart was calibrated between each subject.

3.5 Vertical Ground Reaction Force

3.5.1 Instrumentation and Data Collection

Ground reaction forces were measured using an AMTI, Model OR6-7-1000 force platform (AMTI, Watertown, MA). A four-second sample of the ground reaction forces during step aerobics was collected at the following time points: 0, 1, 2, 3, 4, 5, and 6 minutes. Each four-second sample contained two ground contact phases: (1) stepping off the bench onto the force plate, and (2) stepping off the force plate onto the bench. The force signals (F_x , F_y , F_z , M_x , M_y , M_z) from the AMTI OR6-7-1000 force platform were sampled at 1000 Hz using a National Instruments PCI-6229 16 bit A/D card. A Visual Basic.Net version 2003 computer program was used to sample and analyze the force data.

3.5.2 Data Analysis

A vertical force (F_z) threshold of 6 N was used to identify the start and end of each ground contact. From each ground contact the following variables were computed from the vertical ground reaction force (F_z): peak impact force (BW), impact impulse, and time to peak (ms) (see Figure 3.1, p. 30).

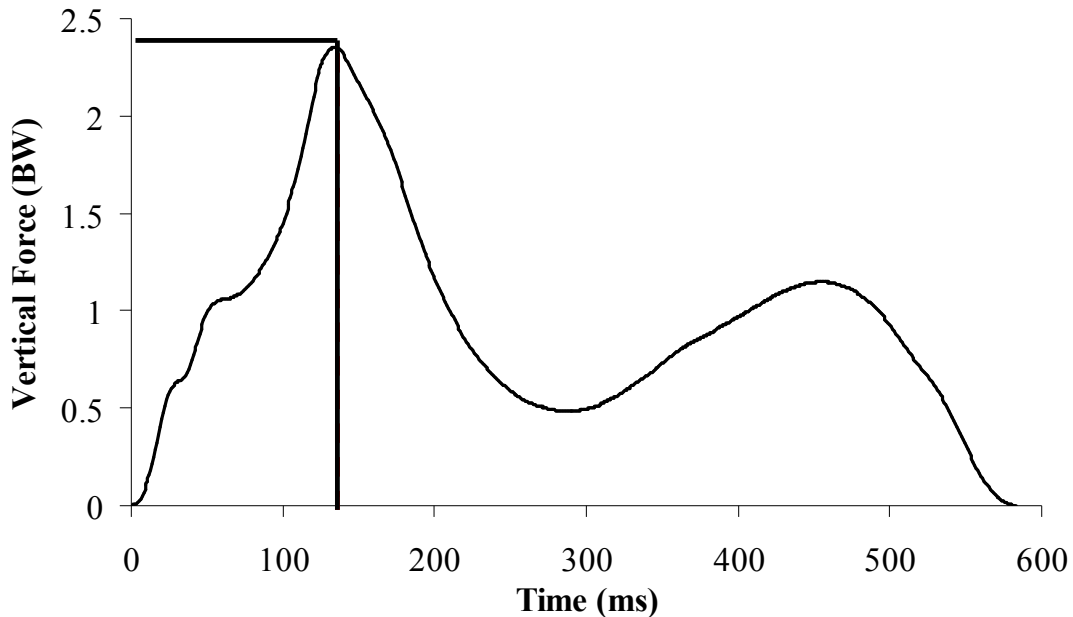


Fig. 3.1 Impact force and time to peak impact force for Subject 2 with a 10-inch bench stepping at a rate of $134 \text{ beats}\cdot\text{min}^{-1}$

3.6 Statistical Analysis

The effect of stepping cadences and bench heights on the averages of HR, VO_2 , RER, caloric expenditure (kcal/min), VGRF, and TPEAK were determined using four separate 2 x 2 analysis of variance (ANOVA) with repeated measures [2 within-subject factors: step cadence (128 and $134 \text{ beats}\cdot\text{min}^{-1}$) and bench height (6 and 10 in.)]. A type I error level was pre-set at 5% ($p \leq 0.05$) and, because there were four analyses, a Bonferroni adjustment was used to protect for the inflation of alpha. The adjustment was $p \leq 0.01$. Analyses were performed using SPSS version 14 (SPSS inc., Chicago,

II). Correlations were used to determine the strength of the relationships among the dependent variables.

CHAPTER 4

RESULTS

The data are presented as mean \pm standard deviation (SD). Although effect size and power calculations did not drive the sample size in the current study, based on previously published data, sample sizes for this type of study usually ranged between 9 and 15 subjects so the current sample size could be considered representative and could result in an adequate effect size to ensure reasonable power for the determination of significant differences that may be present (3,21).

All 12 subjects (N = 12) participated in the testing procedures and completed all the exercise tests. The characteristics of the subjects and the results of the incremental treadmill tests are shown in Table 4.1.

Table 4.1 Subject characteristics and maximal treadmill test results

Variables	Mean \pm SD
Age (yrs)	32.67 \pm 8.24
Body Weight (kg)	66.98 \pm 8.28
Height (cm)	165.75 \pm 12.15
BMI (kg/m ²)	24.28 \pm 2.26
VO _{2max} (ml·kg ⁻¹ ·min ⁻¹)	40.36 \pm 10.72
HR _{max} (beats·min ⁻¹)	178.42 \pm 14.53
RER _{max}	1.08 \pm 0.09

VO_{2max} = maximal oxygen uptake, HR_{max} = max heart rate,
RER_{max} = maximal respiratory exchange ratio reported at the end of the maximal treadmill test.

Table 4.2 reports the physiological responses for each exercise test.

Table 4.2 Steady state cardiovascular, metabolic, and force impact responses to bench step aerobics.†

Variable	128 b/min		134 b/min	
	6 in.	10 in.	6 in.	10 in.
Bench Height				
%VO _{2max} (%)	52.95 ± 14.66	73.92 ± 16.49	57.24 ± 14.81	73.44 ± 23.64
VGRF (BW)	1.58 ± 0.14	1.90 ± 0.24	1.65 ± 0.22	2.02 ± 0.22
TPEAK (ms)	174.93 ± 15.98	155.28 ± 12.13	165.25 ± 14.87	151.47 ± 12.96
KCAL (kcal·min ⁻¹)	6.56 ± 1.31	8.90 ± 2.02	7.13 ± 1.40	9.17 ± 2.01
RER	0.86 ± 0.07	0.93 ± 0.08	0.86 ± 0.07	0.96 ± 0.07

† %VO_{2max} = % maximal oxygen consumption, VGRF = vertical ground reaction forces, RER = respiratory exchange ratio, HR = heart rate, TPEAK = time to peak force, KCAL = caloric cost

Two-way factorial ANOVA with repeated measures revealed no significant differences in VO₂ (p = 0.607) or RER (p = 0.093) between the 2 selected cadences (128 beats·min⁻¹ and 134 beats·min⁻¹); however, a significant difference was observed for HR (p = 0.018) between 128 and 134 beats·min⁻¹. Significant differences between the 2 step heights (6 and 10 in.) were discovered for HR (p = 0.000), VO₂ (p = 0.000), and RER (p = 0.003). There was no interaction between cadence and bench height for any of these dependent variables.

Analysis of the data for time to achieve peak force (TPEAK) at the various bench heights (6 and 10 in.) and stepping speeds (128 and 134 beats·min⁻¹) revealed significant differences ([F (1,11) = 17.045, p = 0.002, power = 0.963] and [F (1,11) = 8.046, p = 0.016, power = 0.733], respectively). There was no significant interaction

between bench heights and stepping speeds ($p = 0.353$) for TPEAK. Figure 4.1 displays a graphic representation of the average TPEAK at each condition.

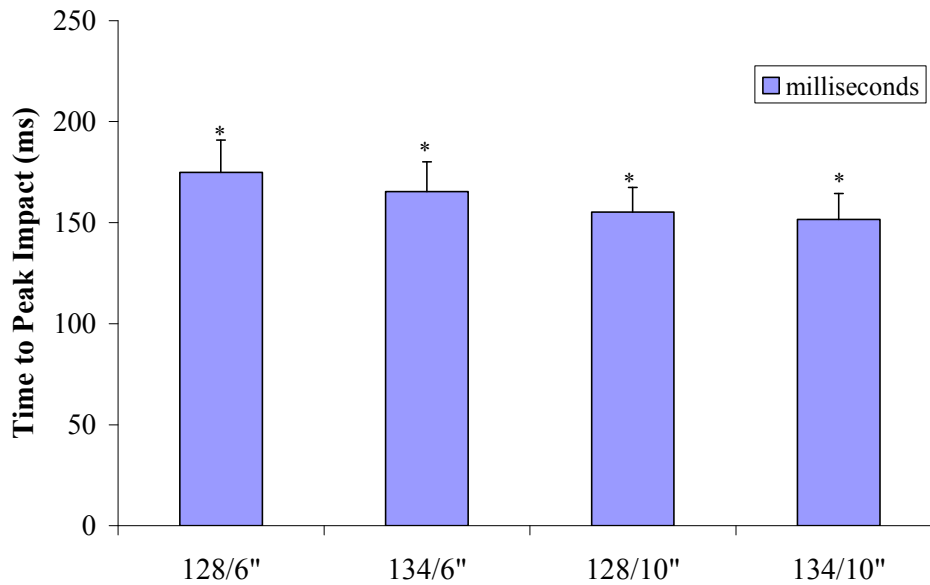


Fig 4.1 Time to peak impact (ms) at 2 different stepping rates (128 and 134 beats·min⁻¹) and bench heights (6 and 10 in.)

* The TPEAK at each condition is significantly different from each other ($p < 0.05$)

Analysis of the data for the vertical ground reaction forces (VGRF) produced at the various bench heights (6 and 10 in.) and stepping speeds (128 and 134 beats·min⁻¹) revealed significant differences for all cadences and bench heights ([F (1,11) = 63.639, $p = 0.000$, power = 1.000] and [F (1,11) = 8.976, $p = 0.012$, power = 0.779], respectively). There was no significant interaction between bench heights and stepping speeds ($p = 0.583$) for VGRF. Figure 4.2 displays a graphic representation of the

average VGRF at each condition.

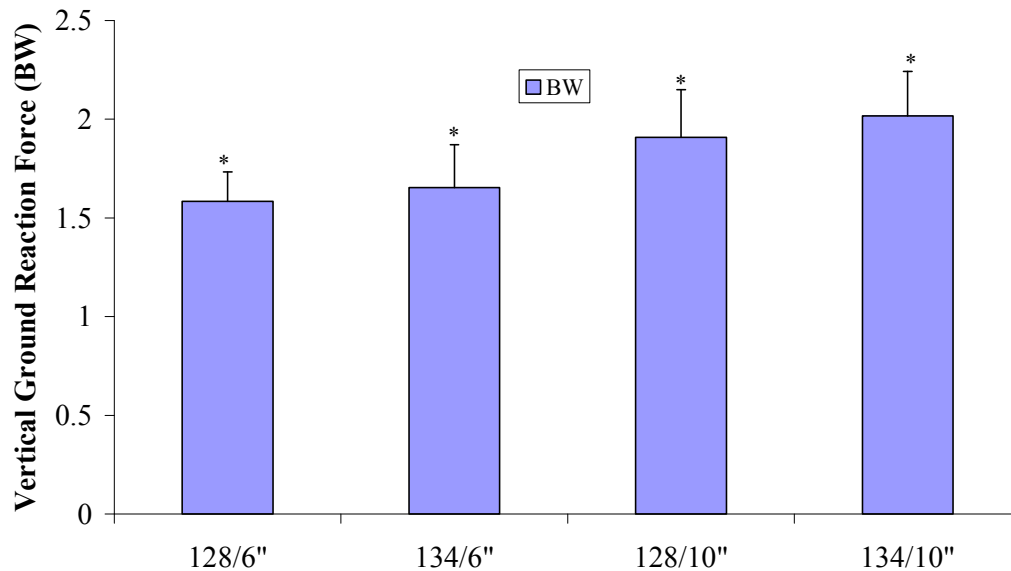


Fig 4.2 Vertical ground reaction force (BW) at 2 different stepping rates (128 and 134 beats·min⁻¹) and bench heights (6 and 10 in.)

* The VGRF at each condition is significantly different from each other ($p < 0.05$)

Analysis of the data for the metabolic cost (KCAL) of the various bench heights (6 and 10 in.) and stepping speeds (128 and 134 beats·min⁻¹) revealed significant differences for all cadences and bench heights ($[F(1,11) = 19.303, p = 0.001, \text{power} = 0.979]$ and $[F(1,11) = 21.100, p = 0.001, \text{power} = 0.986]$, respectively). There was no significant interaction between bench heights and stepping speeds ($p = 0.229$) for KCAL. Figure 4.3 displays a graphic representation of the average KCAL at each (see Fig. 4.3, p. 36).

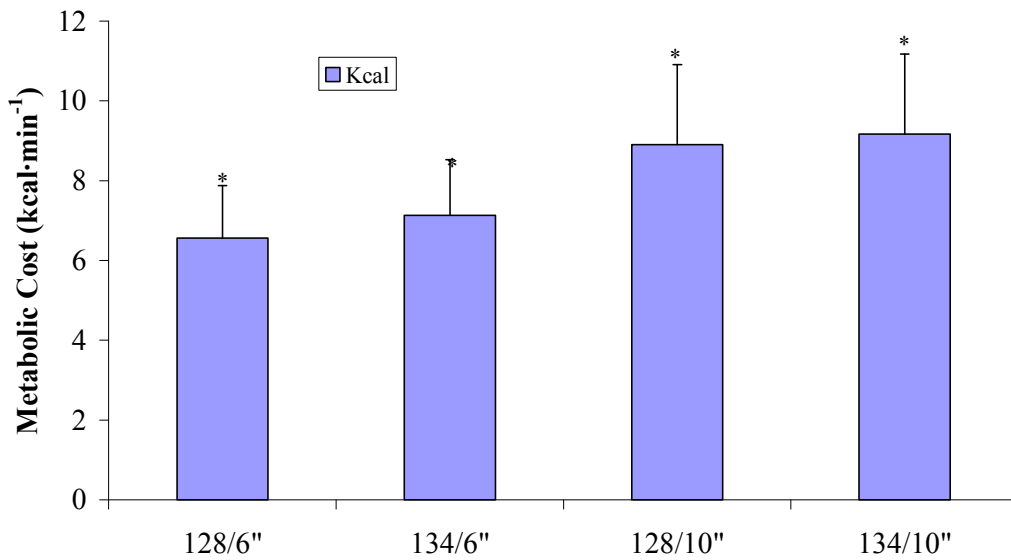


Fig 4.3 Metabolic cost (kcal·min⁻¹) at 2 different stepping rates (128 and 134 beats·min⁻¹) and bench heights (6 and 10 in.)

* The KCAL at each condition is significantly different from each other ($p < 0.05$)

Figure 4.4 depicts a moderate positive relationship ($r = 0.53$) between body weight and the metabolic cost of the exercise condition (see Fig. 4.4, p. 37). As the body weight of the subject increased, the amount of energy required to complete the exercise task increased. In spite of this positive relationship, no relationship existed between the heights of the subjects and the energy cost of the activity ($r = -0.05$). However, a slight negative relationship was discovered between subject height and VGRF ($r = -.31$), though still very low as depicted in Figure 4.5 (see Fig. 4.5, p. 37).

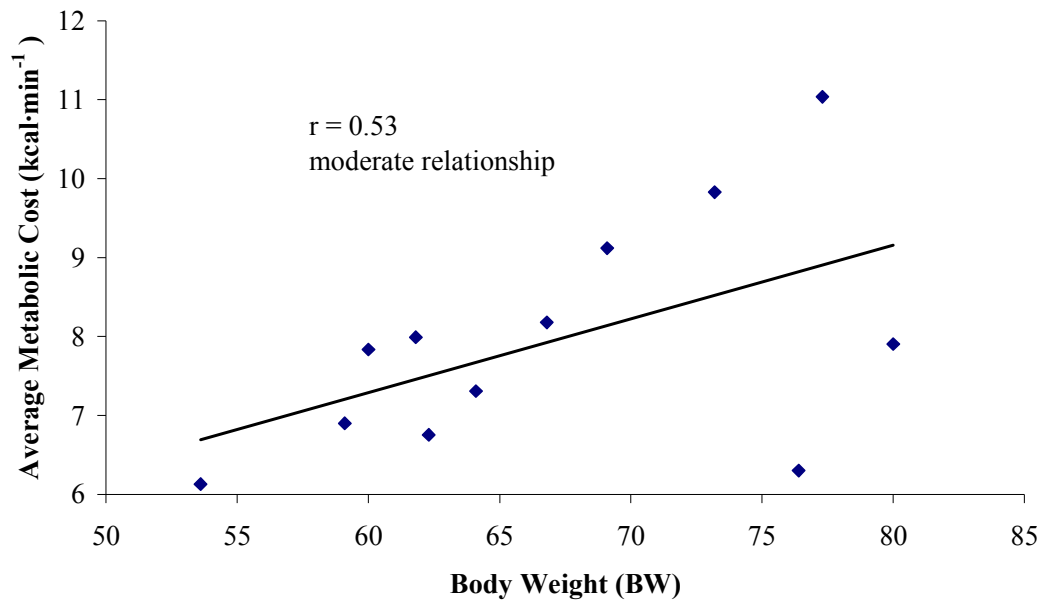


Figure 4.4 Relationship between the body weights of the subjects and the average metabolic cost (kcal·min⁻¹) for each subject across conditions

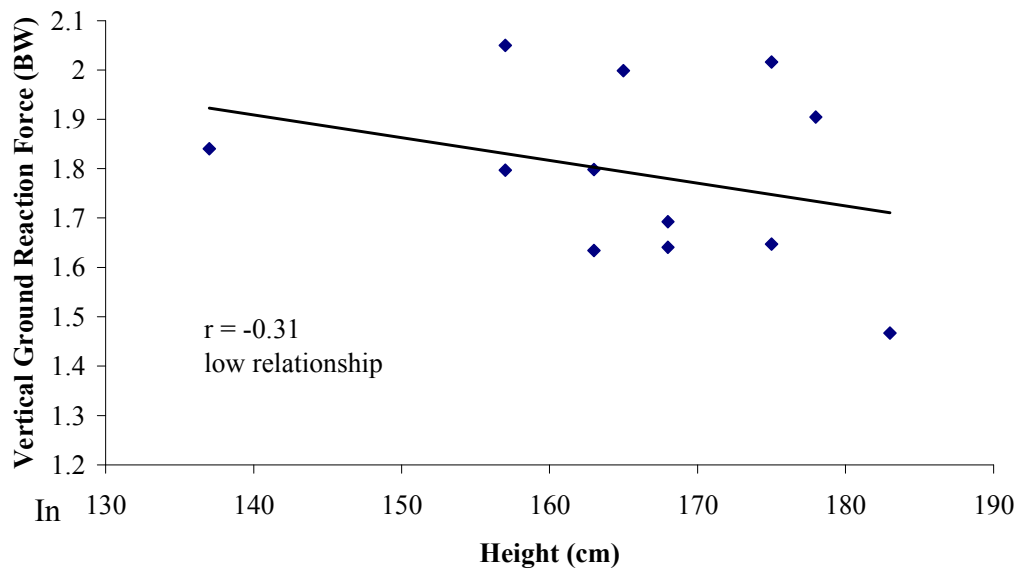


Fig. 4.5 Relationship between the heights of the subjects and the average vertical ground reaction force (BW) for each subject across conditions

In light of these relationships, the variables subject height (SH), subject weight (SW), bench height (BH), and stepping cadence (SC) were entered into a regression analysis to predict force impact and caloric cost. The results of the regression analysis yielded modestly reliable equations for both impact and caloric cost [(R² = 48.3%, SEE = 1.51) and (R² = 48.3%, SEE = 1.51), respectively] (see Table 4.3).

Table 4.3 Results of the regression analyses to predict impact and caloric cost for bench step aerobics.†

	Equation
Impact (BW)	$0.086(\text{BH}) + 0.015(\text{SC}) - 0.004(\text{SH}) - 0.003(\text{BW}) - 0.024^*$
Caloric cost (kcal·min ⁻¹)	$0.547(\text{BH}) + 0.07(\text{SC}) - 0.031(\text{SH}) + 0.109(\text{BW}) - 7.769^*$

† BH = bench height, SC = stepping cadence, SH = subject height, BW = body weight

* R² = 48.3%, SEE = 1.51

CHAPTER 5

DISCUSSION

The purpose of this investigation was to (1) determine the acute metabolic and cardiorespiratory responses of simple bench step aerobics at two cadences (128 and 134 beats·min⁻¹) and two bench heights (6 and 10 inches), (2) calculate the average VGRF and time to peak (TPEAK) at these cadences and bench heights, and (3) attempt to create a regression equation to predict force impact and caloric cost for a given individual based upon physiological height, weight, step cadence, and bench height using the resultant ground reaction forces and metabolic costs. Due to the lack of significant differences between bench heights of 8 and 10 inches in the 1997 study by Maybury and Waterfield, bench heights of 6 and 10 inches were used in this research investigation (21). The stepping rates of 128 and 134 beats·min⁻¹ were chosen as the more common cadences experienced in current BSA classes (34). This study revealed significant differences between both the bench heights and cadences for HR, VO₂, KCAL, RER, VGRF and TPEAK, with no significant interactions between the variables. Heart Rate, VO₂, caloric expenditure, and RER are common measures of exercise intensity and provide a clear indication of the subjects' cardiovascular, respiratory, metabolic, and perceived physiological responses to a given workload.

Both VGRF and TPEAK are good indicators of the injury risk of an activity due to its resultant impact forces. Few studies to date have examined both the metabolic cost and impact forces of BSA with two cadences and two bench heights.

There exists tremendous variability among BSA classes. Choreography, cadence, and intensity are oftentimes the preference of the instructor. The varying proportionate use of the upper body, different step patterns, and even hand-held weights creates a sizeable amount of unpredictability from class to class. While it is possible to evaluate the aerobic and impact requirements of a specific choreographed routine, the results apply only to that design, making it questionable whether the results can be generalized to another class. This study attempted to minimize the number of confounding variables by holding the stepping pattern to a consistent, basic movement, although upper body movement was allowed.

5.1 Effect of Cadence on Metabolic Cost and Force Impact

National aerobic organizations such as AFAA recommend cadences of 118 to 122 beats·min⁻¹ for beginning and intermediate participants and 118 to 128 beats·min⁻¹ for advanced participants (1). By performing BSA at cadences above recommended guidelines, beginning exercise participants may be at increased risk of injury. Bench step aerobics has become a popular form of group exercise. In an effort to create exciting and challenging BSA classes, a recent survey suggests that a majority of group exercise instructors are disregarding safety guidelines and teaching BSA classes at cadences as high as 133 beats·min⁻¹ (34).

Previous research has shown that energy cost of BSA can be altered by stepping rate (16,32). However, research is limited to the metabolic and cardiovascular effects of bench stepping at lower cadences (e.g., 80 and 120 beats·min⁻¹) or higher cadences (e.g., 128 beats·min⁻¹) without arm movements (15,31). Even though physiological differences were found, BSA is not usually performed at these lower cadences or with the hands stationary. Grier et al. failed to show significant differences in physiological responses between the more commonly used cadences of 125 and 130 beats·min⁻¹ in a typical choreographed BSA routine (15). In fact, the authors concluded that BSA classes performed at faster cadences are not only unnecessary for increased physiological benefits, but may also increase the risk of injury as well as intimidate beginning participants (13,15).

This investigation observed significant differences between the two cadences 128 and 134 beats·min⁻¹ for caloric expenditure (kcal·min⁻¹). When stepping rate was increased from 128 to 134 beats·min⁻¹ on a 6-inch bench, caloric expenditure increased by 0.57 ± 0.09 kcal·min⁻¹. This may result in an additional energy cost of approximately 34.2 kcal·min⁻¹ for a 60-minute class. Over the course of a year with participation in three 60-minute BSA classes per week, an individual may utilize an additional 5,335.2 kcal·min⁻¹. This could result in an approximate 1.5 pound loss with each year of participation in BSA by merely increasing cadence. However, if a cadence increase from 128 to 134 beats·min⁻¹ were applied to an individual exercising on a 10-inch bench, the approximate energy cost after one year would equal only 2,524.4

kcal·min⁻¹. This is less than half the caloric benefit of a cadence increase experienced by a participant utilizing a 6-inch bench.

The second consideration of this investigation was the effect of a cadence increase on VGRF and TPEAK. Stanforth et al. observed significant differences between 120 and 128 beats·min⁻¹ on vertical impact forces in both BSA novices and instructors. At 132 beats·min⁻¹, the 1.87 times body weight vertical impact force produced by the instructors' approaches vertical impact forces associated with jogging in women students (18,31). This study recorded significant differences in both VGRF and TPEAK between stepping rates of 128 and 134 beats·min⁻¹, as well. With a bench height of 6 inches, our subjects experienced an increase of 0.07 times body weight for VGRF between 128 and 134 beats·min⁻¹ stepping rates (1.58 ± 0.15 and 1.65 ± 0.22 BW, respectively). For an average 68 kg individual, this would result in a 4.7 kg impact increase. With a bench height of 10 inches, the resultant VGRF increased 0.12 times body weight (1.91 ± 0.24 and 2.02 ± 0.22 BW, respectively). This would result in a 7.5 kg impact increase for a 68-kg individual – almost two times that of the resultant increase on a 6-inch bench. With regards to time to peak force (TPEAK), the reduction with the cadence increase was approximately 4 ms for both the 6- and 10-inch benches. This was still well within the 120 ms time period necessary for musculoskeletal adjustments to occur (174.93 ± 15.98 ms, 165.25 ± 14.87 ms, 155.28 ± 12.13 ms, and 151.47 ± 12.95 ms, respectively).

In summary, an increased cadence on a 6-inch bench amplified the energy cost twice that of the same cadence increase on a 10-inch bench. However, the resultant VGRF values for that same cadence increase on the 6-inch bench were almost half the recorded impact values for an increased cadence on a 10-inch bench. In other words, it appears from this data that an individual may utilize a 6-inch bench but increase the stepping rate from 128 to 134 beats·min⁻¹ and receive a modestly higher metabolic workout with a lessened increase risk of injury from ground reaction forces than an identical workout utilizing a 10-inch bench. Of course, several additional variables must be taken into account when considering an increase in stepping rate. Stanforth et al. determined that body height, body weight, fat free mass, and leg length together with stepping rate significantly affected the oxygen uptake of BSA. Of these five variables, body height and weight were observed to be the most important, accounting for 83% of the variation in oxygen uptake (31).

5.2 Effect of Bench Height on Metabolic Cost and Force Impact

Impact forces and metabolic responses have been shown to increase with bench height (15,21). Grier et al. compared the metabolic and cardiovascular responses between 6- and 8-inch benches. Significant differences were found to exist between the two bench heights for VO₂, HR, and RPE. The model developed in their study indicated that stepping with an 8-inch bench generated a caloric expenditure approximately 1.04 kcal·min⁻¹ greater than a 6-inch bench, resulting in a difference in

energy expenditure of approximately $47 \text{ kcal}\cdot\text{min}^{-1}$ over a 45-minute aerobic session (15).

The data from this study supports the findings of Grier et al. A significant difference in metabolic cost ($\text{kcal}\cdot\text{min}^{-1}$) was observed between bench heights of 6 and 10 inches. At a cadence of $128 \text{ beats}\cdot\text{min}^{-1}$, the energy cost was improved approximately $2.34 \text{ kcal}\cdot\text{min}^{-1}$ between the two bench heights. This may result in an additional energy cost of approximately $140.3 \text{ kcal}\cdot\text{min}^{-1}$ for a 60-minute class. Over the course of a year with participation in three 60-minute BSA classes per week, an individual may utilize an additional $21,892.1 \text{ kcal}\cdot\text{min}^{-1}$, potentially resulting in a 6.25-pound loss with each year of participation in BSA. However, if a height increase from 6 to 10 inches were applied to an individual exercising at $134 \text{ beats}\cdot\text{min}^{-1}$, the additional energy cost after one year would equal $19,000.8 \text{ kcal}\cdot\text{min}^{-1}$, a 5.4-pound loss. Increasing the height of the bench while stepping at a faster rate ($134 \text{ beats}\cdot\text{min}^{-1}$) did not appear to improve the energy cost of the activity as much as a bench increase at the slower speed ($128 \text{ beats}\cdot\text{min}^{-1}$).

The second aspect of this investigation was the effect of a bench height increase on VGRF and TPEAK. With a cadence of $128 \text{ beats}\cdot\text{min}^{-1}$, our subjects experienced an increase of 0.32 times body weight for VGRF between 6- and 10-inch benches (1.58 ± 0.15 and $1.91 \pm 0.24 \text{ BW}$, respectively). For an average 68 kg individual, this would result in a 22 kg impact increase. With a cadence of $134 \text{ beats}\cdot\text{min}^{-1}$, the resultant VGRF increased 0.36 times body weight (1.65 ± 0.22 and $2.02 \pm 0.22 \text{ BW}$,

respectively). This would result in a 24.6 kg impact increase for a 68-kg individual. The time to peak force (TPEAK) was minimally affected bench height increases at cadences of 128 beats·min⁻¹ and 134 beats·min⁻¹ (174.93 ± 15.98 and 155.28 ± 12.13; 165.25 ± 14.87 and 151.47 ± 12.95 ms, respectively).

In summary, an increased bench height at a cadence of 128 beats·min⁻¹ resulted in a greater overall energy cost when compared to a cadence of 134 beats·min⁻¹ with the same increase in bench height. However, the resultant VGRF values for that same height increase at both cadences were similar. In other words, it appears from this data that an individual may utilize a 10-inch bench at a slower stepping rate of 128 beats·min⁻¹ and receive a significantly higher metabolic workout without an increased risk of injury from ground reaction forces when compared to an identical routine utilizing a faster stepping rate of 134 beats·min⁻¹ with the same bench height.

The data clearly reveals metabolic increases with faster stepping rates and higher benches. The VGRF differences between cadences were much greater than those between bench heights, although a comparison of bench heights revealed higher overall VGRF values. It would be expected that VGRF increases with body weight; however, in agreement with Maybury and Waterfield, this was not found to be correct (22). The lighter subjects did not produce the smallest forces. Nevertheless, body weight is directly related to metabolic cost. The heavier subjects produced higher energy cost values when reported in kcal·min⁻¹, supporting the paradigm that caloric cost is related to body weight (15).

When considering a change in exercise intensity through either an increased stepping rate or bench height, individuals must take into account the enhanced injury risk of the activity. Amplified VGRF values have long been suspected as an important aspect in injuries experienced by BSA participants. High impact forces over time will most certainly increase an individual's risk of injury. Additional factors that may be related to injury in step aerobics are eccentric muscle contractions used in stepping up and down on the bench, fatigue, longitudinal loading, aging footwear, leg length, frequency of participation, and exercise surface (20).

It is the conclusions of this author that beginning participants may initially benefit from a slight cadence increase over time, but will eventually need to increase bench height and decrease cadence to continue amplifying the aerobic benefits of BSA exercise. Data from this study shows a definite trend toward a point of diminishing returns in which the risk of injury becomes greater than the caloric benefit (see Fig. 5.1, p. 47). Due to the small sample size, more research is necessary to establish a reliable prediction equation in order to determine those individual parameters for optimal stepping rates and bench heights.

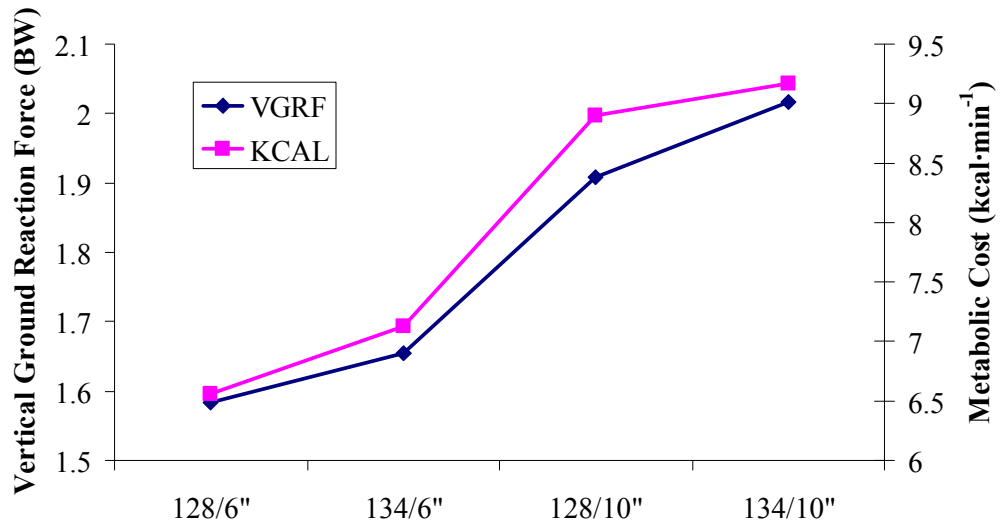


Fig. 5.1 Comparison of average vertical ground reaction forces (BW) and caloric cost ($\text{kcal}\cdot\text{min}^{-1}$) at each condition.

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BIOGRAPHICAL INFORMATION

The author received her Bachelor's degree in English and Secondary Education in 1991 from Dallas Baptist University. After teaching Jr. High English, Reading, and Journalism for seven years, she left teaching to raise her family of three daughters and entered the fitness field part-time as an aerobic instructor and personal trainer. She completed a Physical Fitness Specialist certification from the Cooper Institute for Aerobics Research in 1998 and a Health Fitness Instructor certification from the American College of Sports Medicine in 2001. In addition, she holds various aerobic class instructor certifications for indoor cycling, step aerobics, pilates, kickboxing, and resistance training and certifies personal trainers through the YMCA organization. She began her full-time graduate studies in exercise physiology in the fall of 2005 as a Graduate Assistant. While pursuing her degree, she participated in several research activities involving various aerobic capacity testing modalities, body composition reliability testing, mechanomyography, and stretching. Dianna plans to continue in her full-time position as the Wellness Director of the YMCA of Arlington Cooper Street branch and pursue part-time opportunities in higher level education.