INFLUENCE OF A RACQUETBALL RULE MODIFICATION ON ENERGY EXPENDITURE AND HEART RATE IN AMATEUR PLAYERS

By

JESÚS A. HERNANDEZ-SARABIA

Bachelor of Science in Physical Culture

Benemérita Universidad Autónoma de Puebla

Puebla, Pue. Mex.

2011

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
December, 2016

INFLUENCE OF A RACQUETBALL RULE
MODIFICATION ON ENERGY EXPENDITURE AND
HEART RATE IN AMATEUR PLAYERS

Thesis Approved:

Dr. Timothy Baghurst

Thesis Adviser

Dr. Jason DeFreitas

Dr. Bert Jacobson

AKNOWLEDGMENTS

I will always be thankful to God, without him all the things and objectives that I have achieved would not be possible.

All the professors of Health and Human Performance at OSU have been great. I would like to recognize their time, friendship, and advice. Specifically, Dr. Timothy Baghurst who was always there to guide me through the process of my thesis and also trusted in me to be his graduate research assistant. To Dr. Jason DeFreitas, he was my first professor and the first one to answer any question that I had, moreover, he was always an excellent professor.

To my family, they have always supported me. My mother is a great example and she is always in my mind. Last but not least, my gratitude to Alejandra Barrera, who is always there for me under any circumstance.

Finally, I recognize to CONACYT, without its help I would not have been able to finish my Master's degree.

Acknowledgements reflect the views of the author and are not endorsed by committee members or Oklahoma State University.

Name: JESÚS ALBERTO HERNANDEZ-SARABIA

Date of Degree: DECEMBER, 2016

Title of Study: INFLUENCE OF RACQUETBALL RULE MODIFICATION IN

ENERGY EXPENDITURE AND HEART RATE IN AMATEUR PLAYERS

Major Field: HEALTH AND HUMAN PERFORMANCE

Abstract: Sometimes sports have changed their rules for different purposes. In this study, it was hypothesized that changing a rule might help to increase the energy expenditure, heart rate and some game measurements of Racquetball. The purpose of this study was to measure the influence of rule modification on energy expenditure (kilocalories/min and MET/minute), heart rate reserve percentage (HRR%), percentage of time spent on moderate to vigorous physical activity time (MVPA%), and number of hits per rally. A randomized mini-tournament of six matches was played in two sessions by two amateur high skill players while wearing an accelerometer (ActiGraph GT9X Link) and a heart rate sensor (Polar H6). All the matches were recorded with a GoPro Hero 3+ to measure the number of hits per rally later on. To measure the influence of changing the rule, three conditions were played: two normal matches; two matches with a 1-inch tin, and two matches with a 2-inch tin. After establishing a level of significance of $p = .05$, several two-way chi-square tests were used to analyze all the data and identify if a difference were among the conditions for each of the variables being measured. The only different condition was the 1-inch tin (while comparing it with the no tin condition) which increased the number of hits per rally, X^2 (4, N = 519) = 11.81, $p < .05$, and the time per match. It was concluded that the addition of a 1-inch tin may help to increase the number of hits per rally and time per match. This may help to make the game more attractive and healthier since more time could be expended playing it. Lastly, more studies are needed, with more reliable instruments and different populations, to measure the influence of this rule modification on the variables being measured.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

STATEMENT OF THE PROBLEM

Obesity levels worldwide and within the United States continue to be a concern (Ng et al., 2014); in the United States almost 17 percent of youth and 35 percent of adults are obese. Moreover, with the addition of those overweight, the percentages increase to nearly a third and two-thirds of the youth and adult population, respectively (Ogden, Carroll, Kit, & Flegal, 2014). This is concerning, as overweight and obesity have been linked to premature mortality, heart disease, hypertension, diabetes mellitus, and certain types of cancer (Bombelli et al., 2011; Borrell & Samuel, 2014; World Cancer Research Fund & American Institute for Cancer Research, 2007).

Overweight, obesity, and the aforementioned risks may be reduced through physical activity (American College of Sports Medicine [ACSM], 2013). To guide the quantity and the kind of physical activity recommended for health benefits, organizations such as ACSM (2013) have issued guidelines; for instance, ACSM recommends other aerobic activities of moderate intensity at a minimum of five days per week with a total of at least 150 minutes or high intensity aerobic activities at least three days per week that total 75 minutes. In addition, to improve health and cardiorespiratory fitness of the general population, ACSM recommends spending at least 500-1000 metabolic equivalent (MET)-minute per week, or increasing the number of pedometer steps per day from 2000 to 7000 or more.

Although physical activity has been recommended by organizations like ACSM (2013) and the American Heart Association ([AHA], 2016), the level of physical activity among Americans may not be enough. For example, per the Centers for Disease Control and Prevention (CDC, 2015b), just half of the adults in the United States meet the previously mentioned aerobic physical activity criteria recommended by ACSM. Furthermore, more than a half of those who start exercising drop out within the first 3 to 12 months (Dishman, 1988).

ACSM (2013) guidelines emphasize the principles of exercise prescription, which are: frequency, intensity, time, type, volume, and progression. Regarding type, ACSM (2013) recommends aerobic exercise that involves large muscle groups. To better understand, ACSM (2013) has categorized the types of exercise according to intensity and skill demand. Type A exercises are recommended for all adults because these require low skill and the intensity can be modified easily (e.g., walking, slow dancing). Type B exercises are recommended for those adults with an average physical fitness because they are vigorous and require minimal skills (e.g., jogging, rowing, spinning). Type C exercises are recommended for skilled individuals who have at least an average physical fitness (e.g., swimming, skating). Lastly, Type D exercises are those that are recreational and can be performed to improve physical fitness; the aim of these recreational activities is to be a compliment to Type A through C activities. Type D activities can be performed by any adult if the activity be modified according to skill and fitness level of participants (e.g., racquet sports, basketball, soccer).

Health Benefits of Racquet Sports

Racquet sports, as classified by ACSM (2013), are considered Type D aerobic exercise. Tennis is a common racquet sport in empirical studies, and data concerning its health benefits may transfer to other recreational and competitive racquet sports. In a review, Pluim, Staal, Marks, Miller, and Miley (2007) found lower body fat percentages, increases in high density lipoprotein (HDL), decreases in triglycerides, better aerobic fitness, better bone density, and a reduced risk of cardiovascular morbidity and mortality for those who played tennis as compared with sedentary people.

Similar findings are reported in badminton. In a review conducted by Phomsoupha and Laffaye (2015), badminton players were found to be thin with an average body fat percentage of 11.34, a maximum oxygen consumption (VO_{2max}) of 56.1 mL/kg/min for male players and 47.2 mL/kg/min for female players, and had an average of 90 percent of the heart rate maximum (HR_{max}); these results suggest that badminton may help to improve physical fitness in addition to health.

Unfortunately, little empirical data exists for racquetball, and most of the data is at least 20 years old. Authors like Montgomery (1981), and Morgans, Scovil, and Bass (1984) have reported that racquetball players show a heart rate reserve (HRR) ranging from 67 to 90 percent of the HRR while playing. It also appears that the VO_{2max} of male racquetball players ranges from 46 to 59 $ml/kg^{-1}/min^{-1}$ (Montgomery, 1981; Montpetit, Beauchamp, & Léger, 1987; Morgans et al., 1984; Pipes, 1979; Salmoni, Sidney, Michel, Hiser, & Langlotz, 1991), and racquetball players tend to have a VO_2 consumption of at least 27 $ml/kg^{-1}/min^{-1}$ while playing (Berg et al., 2007; Montpetit et al., 1987).

Benefits of Rule Modifications

Rule modifications provide an opportunity for officials to modify a sport for a specific purpose. For example, the game length and scoring system in badminton, and the introduction of yellow balls or the electronic line-calling in tennis, have both been altered to improve officiating and entertainment for fans (Grahame, n.d.; Hawk-Eye innovations, n.d.; International Tennis Federation [ITF], 2016a; Wright, 2014). According to Arias, Argudo, and Alonso (2011), rule modifications occur for different reasons: a) to improve performance; b) to attract spectators, and attend to commercial pressures and interests; c) to adapt the sport to children; d) to prevent injuries; and e) to attract athletes. Although little is known about racquetball and its rule modification, it is known that racquetball has changed since the early days of paddle racquets in the late 1940's and early 1950's (Sylvis, 1985).

With 12,000 courts available in the United States, racquetball is an easy access sport available for most people (St. Onge, personal communication, February 05, 2016). Nevertheless, compared with recent data to support tennis and badminton as a healthy, beneficial sport (Phomsoupha, & Laffaye, 2015; Pluim et al., 2007), racquetball data is limited and dated. For example, according to Taylor et al. (1978), the energy cost of playing recreational racquetball is 7.0 MET, and the energy expenditure of competitive racquetball is *estimated* to be 10.0 MET (Ainsworth et al., 2011a). It is unclear whether changes to equipment since the 1970s, for example, has impacted these variables. Therefore, it is of value to re-evaluate the energy expenditure in racquetball and determine whether rule modifications might enhance physical activity outcomes.

PURPOSE

The purpose of this study was to measure the energy expenditure and heart rates of amateur competitive racquetball players, and to determine how rule modifications might influence energy expended and heart rate while playing. By understanding energy expenditure and heart rate during competitive racquetball, health-related outcomes through participation in such a sport might be determined. The rule modification proposed in this study may help to increase the number of hits per rally, which in turn may make the game easier to play and more accessible to those with low skills.

Since almost all data regarding energy expenditure and heart rate of racquetball players is dated, research findings will help increase and update the knowledge of energy expenditure and heart rate among racquetball athletes. In addition, a rule modification might increase the energy expenditure and the heart rate of athletes, the number of hits they take per rally, and the percentage of time they are engaged in moderate-to-vigorous physical activity (MVPA). Such increases may improve the health of those participating..

From the limited data available from research in racquetball, it is hypothesized that the energy expended during a racquetball game will be at least 7 MET per minute on average, and HRR will range from 67 to 90 percent; moreover, it is expected that by modifying a rule to require players to hit the ball higher on the front wall of the court, there will be significant increases in energy expended, average HRR percentage, hits per rally, and MVPA percentage time engaged during a racquetball match.

RESEARCH QUESTIONS

1. Will energy expenditure be different with a rule modification?
2. Will hits per rally be different with a rule modification?
3. Will average heart rate percentage be different with a rule modification?
4. Will MVPA percentage time be different with a rule modification?

HYPOTHESES

Null hypotheses:

1. Energy expenditure will not be different with a rule modification.
2. Hits per rally will not be different with a rule modification.
3. Average heart rate percentage will not be different with a rule modification.
4. MVPA percentage time will not be different with a rule modification.

Alternative hypotheses

1. Energy expenditure will be different with a rule modification.
2. Hits per rally will be different with a rule modification.
3. Average heart rate percentage will be different with a rule modification.
4. MVPA percentage time will be different with a rule modification.

SIGNIFICANCE OF STUDY

The information gathered through this study can help identify the average heart rate and energy expenditure of practicing a racquet sport like racquetball at a competitive level. Because these variables may influence health, practicing racquetball may benefit from the game and rule modification. In addition, it may help racquetball organizations consider the pros and cons of rule modification that impact the health and accessibility of those participating. Lastly, those who play recreational racquetball may benefit with the addition of a tin by increasing the time and number of hits per rally during a match. Without this rule change, it is likely that recreational players will try to aim at the bottom part of the front wall which may result in a skip (touching the floor near to the front wall) making the rally shorter.

DEFINITION OF TERMS

Aerobic Exercise: "Activity in which the body's large muscles move in a rhythmic manner for a sustained period of time" (CDC, 2015c, para. 2).

Energy Expenditure: "…results from cellular oxidation of stored energy… can be further ascribed to resting metabolism, thermogenesis of food, and physical activities…" (Kang, 2008, p.129).

Front Wall: Wall that it is in front of the server and receiver while playing racquetball by the time the server is about to start the service movement.

Heart Rate: "The number of times the heart contracts per unit of time, usually expressed as beats per minute." (Brookreson, 2015, para. 2).

Heart Rate Reserve: "Difference between an athlete's maximal heart rate and his or her resting heart rate" (Baechle & Earle, 2008, p. 493).

IRF: The International Racquetball Federation is the governing body recognized by the International Olympic Committee (IOC) that rules over 70 national racquetball federations (International Racquetball Federation [IRF], n.d.-b).

METs: “Equal to 3.5 mL/kg^{-1}/min^{-1} of oxygen consumption” (Baechle & Earle, 2008, p. 494).

Racquetball: “…competitive game in which a strung racquet is used to serve and return the ball” (IRF, 2014, p. 1).

Rally: “All of the play that occurs after the successful return of serve” (IRF, 2014, p. 9).

CHAPTER II

LITERATURE REVIEW

Overweight and Obesity

Overweight and obesity are concepts used to describe people whose weight is higher than the considered healthy weight for a given height (CDC, 2012). Generally, body mass index (BMI) may be used to identify if someone is obese, but caution should be taken since it might not reflect the level of body fatness of a subject (CDC, 2012). For adults, a BMI of more than 25, which is the result of dividing a person's weight by the square of height (kg/m^2), may indicate that the subject has a great amount of body fat, meaning that he/she is overweight (BMI = 25 to 29.9) or obese (BMI of more than 30) (CDC, 2012).

In the United States, almost one-third of the youth population is overweight or obese: the trends for the adult population are higher with more than two-thirds being overweight or obese (Ogden et al., 2014). It is estimated that the annual medical cost of obesity to the U.S. was $147 billion in 2008 (CDC, 2015a). Not only is obesity related to more expenses, it has been linked to heart disease and certain types of cancer (CDC, 2015a), which account for almost half of all deaths per year (Johnson, Hayes, Brown, Hoo, & Ethier, 2014), in addition to diabetes, strokes and hypertension (National Heart, Lung, and Blood Institute [NHLBI], 2013).

Borrell and Samuel (2014), after controlling for age, gender, race, education, smoking and leisure time/physical activity, found that those with grade II and III obesity are at least 41 percent more likely to die of any cause 3.7 years sooner than those who have a normal weight. In addition, they found that after controlling these variables, those who are obese are at least 20 percent more likely to die of cardiovascular disease (CVD) when compared with those who are of normal weight. The percentage also increases as the obesity grade increases.

The World Cancer Research Fund and the American Institute of Cancer Research (2007), after performing a series of meta-analyses, found that the increase of 5 kg/m^2 over the normal weight increases the chances of having pancreatic cancer to 14 percent when compared with those of a normal weight. In the case of colorectal cancer, they found that on 28 cohort studies, the average effect size was of three percent per kg/m^2. Therefore, if a linear relationship is assumed, the likelihood of having colorectal cancer increases 15 percent for each increment of 5 kg/m^2 when comparing overweight/obesity with normal weight.

The World Cancer Research Fund and the American Institute of Cancer Research (2007) found that the probabilities of having breast cancer when there is an increment of 2 kg/m^2 are at least one percent when compared with those having a normal weight. Nevertheless, the probability increases on postmenopausal women when compared with those with normal weight, and such an increment is from three percent (as showed on cohort studies) up to five percent (as showed on case-control studies) for the same amount of increment in kg/m^2. Endometrial cancer may be more likely for those who are overweight or obese, and the possibilities of having this kind of cancer increases from 52 percent to 56 percent per each 5 kg/m^2 increments over the normal weight. Lastly, chances of having kidney cancer increase at least 31 percent per each 5 kg/m^2 increment over the normal weight.

Physical Activity

Obesity is linked to at least two of the leading causes of mortality in the United States (Johnson et al., 2014). That is why, among other reasons (e.g., the amount of money spent by the government for healthcare), reducing levels of obesity is important. Fortunately, obesity may be reduced through physical activity since it helps to increase the energy expenditure (ACSM, 2013). To be healthy and contribute to weight loss, ACSM (2013) recommends aerobic activity of moderate to vigorous intensity at least five days a week for a minimum of 30 minutes a day. In addition, they recommend performing resistance training and flexibility exercise for a balanced exercise program.

Certainly, physical activity may help to decrease the levels of obesity, but it has not been recommended for just that. Physical activity has several health-related benefits; for example, according to the Physical Activity Guidelines Advisory Committee (2008), there is an inverse relationship between physical activity and all-cause mortality, CVD, coronary heart disease (CHD), stroke, hypertension, type 2 diabetes, osteoporotic fractures, osteoporosis, falls in older adults, certain types of cancer, depression, and anxiety.

For health benefits related to physical activity, it is important to meet criteria concerning frequency, intensity, time, type, volume, and progression of exercise (FITT-VP principle of exercise prescription proposed by ACSM). According to ACSM (2013), an exercise prescription should include resistance exercise, flexibility, neuromuscular fitness, and aerobic exercise. Resistance exercise should be performed at least two days a week per each major muscle group, with intensities from 60 to more than 80 percent of 1-RM (repetitions maximum) for adults and a minimum of two sets of eight to twelve repetitions. Flexibility exercises should be performed at least twice a week for 10 to 30 seconds per repetition and a total volume of 60 seconds. Neuromuscular fitness involves exercises such as balance, coordination, gait, agility, and proprioceptive training; it should be performed at least twice weekly for at minimum 20 minutes (ACSM, 2013).

Lastly, adults should perform three to five days a week of aerobic exercise where the frequency will depend on the intensity and variety of exercises or activities (ACSM, 2013). Vigorous activity performed in a daily manner may result in an injury; nevertheless, the addition of different activities may diminish the likelihood of injury (ACSM, 2013). A variety of ways to evaluate the intensity of exercise exist, but ACSM (2013) recommended that it is measured with relative methods as heart rate reserve (HRR) and oxygen uptake reserve (VO_2R). Moderate (40% to < 60% HRR or VO_2R), and/or vigorous (60% to < 90% HRR or VO_2R) aerobic exercise should be performed by almost all adults. Adults should do bouts of at least 10 minutes to accumulate 30 to 60 minutes a day of moderate activity (at least 150 minutes a week), 20 to 60 minutes a day of vigorous activity (at least 75 minutes a week), or a combination of both intensities to meet the duration of exercise needed. Aerobic exercise that involves large muscles should be performed with any of the types of exercises mentioned earlier (Type A, B, C, or D). In addition, at least 500 to 1000 METs-minute per week should be spent, which is approximately equal to 1000 kcal a week.

Measuring Energy Expenditure

Total energy expenditure is influenced by resting metabolism, thermogenesis of food, and physical activity (Kang, 2008). Resting metabolism may be influenced by body size, body composition, age, level of fitness, sleeping time, smoking, and caffeine (Kang, 2008).

Energy is "the ability to produce change by the amount of work performed during a given chance" (Kang, 2008, p. 3). Energy is not created by the body; on the contrary, the body obtains energy from food nutrients which are stored as glycogen and/or triglycerides (as a way of energy) to be used later (Kang, 2008).

Energy is transformed from macronutrients available in food to chemical compounds like adenosine triphosphate (ATP), phosphocreatine (PCr), glycogen, and triglycerides (Kang, 2008). Each of these compounds except ATP is used to replenish ATP, which is an essential compound to yield energy, through three energy systems: a) ATP-PCr system; b) glycolytic system; and c) oxidative system (Kang, 2008). To measure energy expended, there are three main methods: a) laboratory methods; b) field methods (Kang, 2008; Montoye, Kemper, Saris, & Washburn, 1996); and c) subjective methods (Kang, 2008).

Questionnaires and diaries are subjective methods (Kang, 2008). Nevertheless, because they are inexpensive and can be applied to many subjects at the same time (Kang, 2008; Montoye et al., 1996), they can be useful when studying a vast array of subjects. Questionnaires can be executed through self-administration or by interviewing the participants (Montoye et al., 1996). This instrument is always used to assess participants' activities during the last day, week, month, or year (Montoye et al., 1996) through recall (Kang, 2008). Generally, questionnaires have certain limitations including accuracy when recalling, overestimation or underestimation of intensity and time (Kang, 2008), and energy expenditure estimation (Lee, Macfarlane, Lam, & Stewart, 2011; Montoye et al., 1996). Diaries are used by the evaluated participants to frequently record their activities during a certain amount of time (Kang, 2008; Montoye et al., 1996), and the information collected by questionnaires can be analyzed. Diaries have limitations such as a lack of accuracy if administered over a long period and an influence directed by the participants' behavior (Kang, 2008; Montoye et al., 1996; Welk, 2002).

Laboratory methods may be the most precise when measuring energy expenditure. Nevertheless, these types of tests are not realistic because all the activities in life are performed in an uncontrolled environment (Welk, 2002). Usefulness of laboratory methods assumes that they are more accurate, in which case field methods can be compared with criterion measurements gathered by performing procedures conducted in the laboratory (e.g., Rousset et al., 2015).

Calorimetry is a laboratory method based on the assumption that the body exerts heat through cellular respiration and mechanical work when using energy (Kang, 2008). Direct and indirect calorimetry are the two ways to measure heat production (Kang, 2008). The direct method is performed in an enclosed chamber with an exercise device, and the participant exercises in the chamber, while the amount of heat is measured through heat exchangers with water that absorbs the heat (Kang, 2008). Indirect calorimetry assumes that, since almost all the energy process into the body depends on oxygen, the energy can be measured through the gas exchange of the participant being tested (Montoye et al., 1996). To measure the energy expended during indirect calorimetry, it is necessary to know the quantity of oxygen consumed and carbon dioxide produced (respiratory quotient) through spirometry (Kang, 2008; Montoye et al., 1996). In addition, to know the quantity of energy expended by liter of oxygen consumed, it is necessary to know the quantity of kilocalories produced from fats (4.68 kcal) and carbohydrates (5.05 kcal); proteins are not considered since they do not contribute at all to energy metabolism (Kang, 2008). The ratio quotient will give a value from 0.7 to 1.0, and the higher the value, the more the energy is produced (Kang, 2008; Montoye et al., 1996).

Field methods are used to measure energy expenditure during free-living conditions (Kang, 2008). Doubly labeled water, motion sensors, and heart rate monitors may be the field techniques most used (Kang, 2008). Doubly labeled water, which contains a known concentration of ^{2}H and ^{18}O, is drunk by the participant to know the quantity of ^{2}H and ^{18}O eliminated through urine (Welk, 2002). By knowing the quantity of ^{2}H and ^{18}O eliminated, in addition to carbon dioxide (CO_2), daily energy expenditure can be measured (Kang, 2008; Welk, 2002). Although doubly labeled water may be accurate, it has some disadvantages including the cost of ^{18}O, requirement of ratio mass spectrometer, participants with experience using it, and lack of information regarding energy expenditure during brief periods or about specific activities (Montoye et al., 1996).

Motion sensors can measure energy expenditure by capturing data about motion, and/or the acceleration of a limb or the trunk (Kang, 2008). Pedometers and accelerometers are the most used motion sensors; while pedometers basically measure distance and the number of steps when walking, accelerometers measure the acceleration produced during movement (Kang, 2008; Welk, 2002).

Since a linear relationship exists between the heart rate and the oxygen consumed, heart rate monitors are often used to measure energy expenditure (Kang, 2008). Heart rate monitors are not as expensive and as invasive as other methods (Kang, 2008). In addition, they are affordable and accessible.

Rationale for Using Accelerometers and Heart Rate Monitors

Accelerometers can be uniaxial (one plane) or triaxial (three planes) (Kang, 2008). According to Kang (2008), accelerometers' advantages are their portability and their capacity to detect movement, intensity, duration, and frequency. Lastly, since accelerometers can measure intensity and duration of physical activity, conclusions can be made regarding health outcomes (Kang, 2008).

Heart rate monitors' advantages include the close correlation with VO_2 (especially when the heart beats from 110 to 150 beats per minute), an ability to provide information regarding intensity, frequency, and duration of exercise (Kang, 2008; Welk, 2002), and its low cost (Kang, 2008). Heart rate monitors are worn on the chest (transmitter), which transmits the R-R waves of electrocardiography (ECG), and the wrist (signal receiver), which displays the heart rate in beats per minute (Kang, 2008).

In the market are several motion sensors with the ability to measure heart rate and energy expended, but for research purposes accurate instruments to measure acceleration, heart rate, and energy expended while performing physical activity are necessary. One of the brands largely used in the health field is ActiGraph with several studies among the scientific community (e.g., Hänggi, Phillips, & Rowlands, 2013; Robusto & Trost, 2012). Validity of ActiGraph accelerometers has been reported while running at different speeds and its correlation with VO_2 (r = 0.81 – 0.88, p <.01) (Kelly et al., 2013). In addition, its reliability, specially for moderate to vigorous physical activity (MVPA [Interclass correlation = 0.99, absolute percent error = 3.7%, and coefficient of variation = 4.9%]), during free-living conditions has also been reported (McClain, Sisson, & Tudor-Locke, 2007).

Racquet Sports

Racquet sports, as classified by ACSM (2013), pertain to Type D aerobic exercise, which are those that are recreational and may be used as a complement to meet the exercise prescription guidelines. In a literature review regarding tennis, Pluim and colleagues (2007) found that in singles games, the mean heart rate was 70 to 90 percent of HR_{max} and a 50-80 percent of VO_{2max}. In addition, aerobic capacity of the players ranged from 35.5 to 65.9 mL/kg/min. In addition, Pluim and colleagues (2007) reported that in the studies reviewed by them, the percentage of body fat was significantly lower, and the HDL levels were significantly higher for those who practice tennis when compared with the general population.

Lastly, in a review conducted by Phomsoupha and Laffaye (2015), badminton players had an average 11.34 percent of body fat, an average VO_{2max} of 56.1 mL/kg/min for male players and 47.2 mL/kg/min for female players, and an average of 90 percent of the HR_{max} when playing.

History of Racquetball

According to the International Racquetball Federation (IRF, n.d.-a), racquetball is a sport where “players compete in singles and doubles… with the objective of returning the racquetball to the front wall before allowing it to bounce twice on the floor” (para. 2).

Racquetball and its deepest roots are influenced by the Spanish sport “jai alai” during the seventh century (Turner & Hogan, 1988). Later, in the thirteenth century, a game with a ball that could be tossed or hit with the hand was played in Europe; its progression continued through the fifteenth and sixteenth centuries when a primitive racquet was used to hit the balls (Turner & Hogan, 1988).

Besides the European roots of racquetball, the sport was influenced by other sports such as tennis, squash, Irish handball, and other ball-hitting games in Europe (Turner & Hogan, 1988), but the origin of the sport was in the United States of America in the early 1950s (Morgenstern, 1980; Sylvis, 1985; Turner & Hogan, 1988; Verner, 1992). The creator of this sport was Joe Sobeck, who was looking for a different exercise; therefore, he designed a different racquet with strings, and he called this sport “paddle rackets” (Morgenstern, 1980; Sylvis, 1985; Turner & Hogan, 1988; Verner, 1992).

The popularity of “paddle rackets” increased slowly at first, and it was not until the late 1960s when its popularity started to grow (Turner & Hogan, 1988). Proof of that was the first national paddle rackets championship in 1968 and a year later the first international paddle rackets championships (Turner & Hogan, 1988). In those days, the name of “paddle rackets” was changed to “racquetball” and around those same years several organizations were created (Turner & Hogan, 1988).

The first racquet was developed by Sobeck because he wanted a string racquet instead of a wooden racquet (Turner & Hogan, 1988); since that day, the racquet has evolved from the introduction of aluminum frames in 1971 and fiberglass frames a year later to the oversized frames in 1984 (United States Olympic Committee [USOC], n.d.-a, Evolution of the Racquet section, para 2).

Today, the governing body for all the sanctioned racquetball events among the world is the International Racquetball Federation, which was formed in 1979 and recognized by the International Olympic Committee (IOC) in 1985 (IRF, n.d.-b para. 1). In the US, the governing body is the United States Association of Racquetball (USAR) which is also recognized by the USOC (n.d.-b).

The Game, Court, and Equipment

Racquetball is a game played in two modalities: a) singles (1 versus 1); and b) doubles (2 versus 2) (IRF, 2014). The ball is served and returned with strung racquets (IRF, 2014), and the objective of the game is to win each rally, which occurs after the return of serve until the opponent or team fails to keep the ball in play (IRF, 2014). The ball remains in play as long as: a) it does not touch the floor twice; b) it touches the front wall prior bouncing on the floor when returning the ball; and c) no hinder is called (IRF, 2014).

The game starts as soon as the ball leaves the server's hand, and in order to serve the ball has to bounce on the floor and must be hit by the server (IRF, 2014). Once the ball has been hit by the server, it must bounce on the front wall prior touching the floor area delimited by the short line and the back wall. By doing so, the ball can touch one of the side walls (IRF, 2014). The receiver must hit the ball in order to touch the front wall. To do this, the receiver can hit the ball after bouncing once on the floor or on the fly, and by doing so, the ball can touch the side or the back wall, and/or the ceiling (IRF, 2014).

A racquetball match is made up of two games with 15 points each and, in case of a draw, a third game of 11 points, called a tiebreaker, is played; the player or team that wins two games is the winner of the match (IRF, 2014). To score a point the serving side must win a rally; if the serving side loses the rally, a sideout (second serving side in doubles or any serving side in singles) or handout (first serving side in doubles) is called and the serve is lost with no point scored by any of the teams or players (IRF, 2014).

According to the IRF (2014), the racquetball court must measure 20 feet wide, 40 feet long, and 20 feet high with a back wall of at least 12 feet high; markings must be 1.5 inches wide to delimit: a) short line; b) service line; c) service zone; d) service boxes; e) drive serve lines; f) receiving line; g) safety zone; and h) out of court line.

The equipment needed for playing racquetball includes: a) ball; b) racquet; and c) eyewear (IRF, 2014; Morgenstern, 1980; Sylvis, 1985; Turner & Hogan, 1988; Verner, 1992). According to the IRF (2014), the ball must be: "…$2\frac{1}{4}$ inches in diameter; weigh approximately 1.4 ounces; have a hardness of 55-60 inches durometer; and bounce 68-72 inches from a 100-inch drop at a temperature of 70-74 degrees Fahrenheit" (p. 3). The racquet cannot be more than 22 inches in length and must have a cord to be worn on the player's wrist. Racquet strings must be gut, monofilament, nylon, graphite, plastic, metal, or any combination of these materials (IRF, 2014). Eyewear is used to protect the players' eyes and must be manufactured for racquet sports (IRF, 2014).

Racquetball Benefits Related to Health

Unfortunately, few studies have investigated the health-benefits of racquetball participation; moreover, the few studies that have studied the cardiovascular, muscular and flexibility effects of racquetball are from the 1980's, 1990's, and just one from 2007. Therefore, considering the limited physiological data available, combined with the transformation in equipment over the past several decades, it is unclear how racquetball may influence health.

Heart rate responses to racquetball have been reported (Montgomery, 1981; Montpetit et al., 1987; Morgans et al., 1984; Pipes, 1979; Salmoni et al., 1991). Montgomery (1981) used the Karvonen formula and found that when a game is between players with equal ability, their HRR increased up to an 87 percent. When the game is between players of different levels their percentage of HRR tend to be different, with a maximum of 90 percent of the HRR for the less skilled, and a maximum of 70 percent of HRR for the more skilled. Morgans and colleagues (1984) found that in singles most of the time HRR during the game was from 67 to 89 percent, with an average of 83 percent of HRR. Other authors have reported the heart rates as percentage of heart rate maximum with a range of 76 to 92 percent (Montpetit et al., 1987; Pipes, 1979; Salmoni et al., 1991); due to this, their findings cannot be compared with the ACSM recommendations but appear to support the suggestion that racquetball should be considered a vigorous exercise.

In a study conducted by Montgomery (1981), racquetball matches lasted from 34 to 50 minutes depending on the level of skill or ability of the players. Pipes (1979) stated that a racquetball match normally lasts from 60 to 75 minutes. Although little is known about the duration of a typical match, it appears that it lasts at least 50 minutes, which fits the recommendations of the ACSM (2013) about the duration of exercise.

Strength and flexibility improvements of racquetball have only been investigated by Pipes (1979), which evaluated racquetball professionals' flexibility with the sit-and-reach test and strength with back hyperextensions, supine bench press, leg press, biceps curl, and shoulder press. It was concluded that flexibility of professional players was less than other sports, strength in the upper body was no different when compared with nonathletes of the same age, but lower body strength was significantly higher when compared with the previously mentioned population. In a study related to squash, Hashem Mohammed (2013) measured the effect of a 12-week intervention of squash training twice a week. After pretest and post-test, flexibility measured with the sit-and-reach test increased from 24.73 to 26.70 centimeters. Although there was a change, there was no control group and nothing is known about the influence of pretest to post-test; therefore, the results must be considered carefully.

Little research has been conducted about the influence of racquetball on VO_{2max} which, according to Beachle and Earle (2008), is “the amount of oxygen that can be used at the cellular level for the entire body” (p.123). In five articles, VO_{2max} of different male populations was measured to describe the characteristics of those subjects (Montgomery, 1981; Montpetit et al., 1987; Morgans et al., 1984; Pipes, 1979; Salmoni et al., 1991). Pipes (1979) found that professional racquetball players have a mean VO_{2max} of 58.3 $ml/kg^{-1}/min^{-1}$. Montpetit and colleagues (1987) found that racquetball players of intermediate ability (e.g., C level) have a VO_{2max} of 54.1 $ml/kg^{-1}/min^{-1}$. These results are consistent with Montgomery (1981), who found that depending on skill level, VO_{2max} would be 54-56 $ml/kg^{-1}/min^{-1}$, being the 54 $ml/kg^{-1}/min^{-1}$ value for those at level C. Lastly, the study conducted by Morgans and colleagues. (1984) found that the mean VO_{2max} of the population was 46.2 $ml/kg^{-1}/min^{-1}$. These results are consistent with Salmoni and colleagues (1991), who found a VO_{2max} of 46.5 $ml/kg^{-1}/min^{-1}$ for male and 40.6 $ml/kg^{-1}/min^{-1}$ for female participants.

Two authors have measured the VO_{2max} during a racquetball game (Berg et al., 2007; Montpetit et al., 1987). Montpetit and colleagues (1987) found that 51 percent of

VO_{2max} was used during the racquetball games. While Montpetit and colleagues (1987) did not mention the value corresponding to 51 percent, such a value can be inferred through the VO_{2max} of the population (54.1 $ml/kg^{-1}/min^{-1}$) given by Montpetit and colleagues (1987), which was 27.6 $ml/kg^{-1}/min^{-1}$. This result appears to coincide with the results of Berg and colleagues (2007), which showed that the mean VO_2 of playing racquetball during 40 minutes is 27.3 $ml/kg^{-1}/min^{-1}$.

Bartoli and colleagues (1994) wanted to know the effect of a 12-week racquetball program on VO_{2max}, body composition, plasma lipid, and lipoproteins concentrations. For study purposes, 16 college-age male students were in a control group (CG) or an intervention group (IG), and the pretest consisted of measuring the aforementioned dependent variables. After the 12-week intervention, which consisted of three sessions per week (10-15 minutes warm up and 30 minutes of playing), the dependent variables were measured again. The results showed no statistically significant differences in VO_{2max}, body weight, and percentage of body fat. However, the lean body weight, and mean plasma total-cholesterol concentrations were significantly lower for the IG compared with the CG. The authors concluded that, although the changes on VO_{2max} were not statistically significant, there was a slight increase. In fact, after the twelve weeks, the lack of a significant increase could be because the IG showed a high VO_{2max} (51.4 $ml/kg^{-1}/min^{-1}$) before the intervention.

In conclusion, racquetball is a physical activity that lasts between 34 to 75 minutes, with HRRs from 67 to 90 percent and an average HRR of (83-87 percent). These values meet the recommendations of ACSM (2013) for quantity of vigorous exercise (20 to 60 minutes a day). Strength and flexibility may not be affected directly by racquetball (with exception of lower body strength) but more studies are needed to affirm it since squash has shown flexibility improvements (Mohammed, 2013). Maximal oxygen uptake is the most used criterion to measure cardiorespiratory fitness (CRF), which is the ability to perform during prolonged periods of moderate to vigorous exercise (ACSM, 2013). In regards, racquetball influence on VO_{2max} has not been studied; nevertheless, almost all studies have reported a $VO_{2\,max}$ of 46.5-58 $ml/kg^{-1}/min^{-1}$ for male players. The VO_{2max} of racquetball players can be categorized from good to superior CRF.

These studies should be considered with caution. Changes in rules and equipment over the past several decades may have affected the legitimacy of these findings. Therefore, it becomes important to investigate if and how newer equipment and the modification of rules affect physiological variables associated with health.

Change of Rules in Racquet Sports

Game modification has been a concern during the last twenty years (Arias et al., 2011). One way to modify a sport is by changing the rules, which, according to Parlebas (1999, as cited by Arias et al., 2011), would determine the relationship of participants with other players, with game space, with equipment, and with time.

According to Arias et al. (2011), rules can be divided by those that refer to the internal logic of the game and those about the external logic. Internal logic rules can be divided on structural, which are measurable (e.g., space, time, equipment, number of players), and functional, which determine obligations, rights, and prohibitions. External logic rules are those about nonessential elements that, although influential to the game, do not determine its continuity (e.g., scoring system, characteristics of material, uniforms).

Rules can be changed with different purposes in mind. The objectives of such a change in rules can be: a) to improve performance; b) to attract spectators, and attend to commercial pressures and interests; c) to adapt the sport to children; d) to prevent injuries, and e) to attract athletes (Arias et al., 2011). With these objectives in mind a variety of racquet sports have changed their rules over time. For example:

- Rules of badminton changed in 2006 to make it more exciting for TV audiences (Grahame, n.d.). These rules included a change in game length, scoring system (prior modification, points were only given on serve as in racquetball) (Grahame, n.d.; Wright, 2014), and break time (Wright, 2014). Later, Percy (2009) confirmed that the new rules were fairer than the older ones, and led to faster and more exciting games.
- The number of services by server before changing the service, and the number of necessary games and points to win a match and game was changed in table tennis in 2001 (Wright, 2014). By probabilistic simulation, Coupet and Gerville-Réache (2007) found that when playing 11 points per set, the probabilities of winning a point by the player who is losing was higher than the one that was winning. Thus, the probability of turnarounds or changes in momentum was higher, which could be interpreted as a more interesting and balanced game.
- The change of rules has also been seen in tennis: the eight-week rule was established in 1951; the first changes in scoring and the tiebreak were seen from 1970 to 1988; the use of yellow balls instead of white balls started in 1972; the two-bounce rule for wheelchair players was adopted in 1988 (ITF, 2016a); and the introduction of Type 1 and 3 balls in 2002 (ITF, 2016b). In addition, the use

of technology such as the introduction of electronic line-calling to help decide if a ball has bounced in or out, and SMART replay to assist official on foot faults or line calls began in 2002 (Hawk-Eye innovations, n.d.).

Rule modification information on racquetball is limited. Nevertheless, some of them were made or modified for safety of the game, and others to make it more interesting for the players and the people (St. Onge, personal communication, February 05, 2016). According to United States Racquetball Museum (2012), some of the changed rules were: a) 21 points to 15 points per game; and b) a mandatory eye guard rule. In addition, according to Baghurst (personal communication, August 18, 2016), the "one serve" rule has recently changed to two serves in international competitions; moreover, the timeouts and time between games have also been changed (personal communication, August 2, 2016). Although other changes have been made, such as the material change on racquetball frames, the "ultra blue" ball, and the all-glass portable court, it is not clear if those adaptations were because of a rule modification.

Purpose

The purpose of this study is to measure the energy expenditure and heart rates of amateur competitive racquetball players, to determine how rule modifications might influence energy expended and heart rate while playing. By understanding energy expenditure and heart rate during competitive racquetball, health-related outcomes of participating in such a sport might be determined. Furthermore, the rule modification proposed in this study may help to increase the intensity and duration of the game. In addition, rule modification may make the game easier to play and more accessible to those with low skills as no bouncing on the bottom edge of the front wall may be permitted.

Since almost all the data regarding energy expenditure and heart rate of racquetball players is dated, research findings will help increase and update the knowledge of energy expenditure and heart rate among racquetball athletes, in addition, rule modifications might increase the energy expenditure and the heart rate of athletes, the rally length, and the MVPA percentage of time while playing to make the game healthier. As a consequence, it is hypothesized that the energy expended during a racquetball game will be at least 7 MET (7 kcal approx.) per minute on average, and a HRR ranging from 67 to 90 percent; moreover, it is expected that by modifying a rule, and requiring players to hit the ball higher on the front wall of the court, will significantly increase the energy expended, average HRR percentage, rally length, MVPA percentage time during a racquetball match. Lastly, those who play recreational racquetball may benefit with the addition of a tin by increasing the time and number of hits per rally of a match. Without the change of rule, it is likely that recreational players during a match will try to aim for the bottom part of the front wall, and this may cause a skip (touching the floor near to the front wall) thereby making the rally shorter.

CHAPTER III

METHODOLOGY

PARTICIPANTS

An experimental quantitative design for this study was convenience sampling. Since skill level has more variation among recreational players and the rule modification may not influence the variables being measured on recreational subjects, two recreational but competitive racquetball players from the United States were part of the study. Participants were recruited through personal contacts (e-mail or phone). The two participants were of an “open skill level,” which is the highest amateur level in racquetball. Participants had no previous history of injury in the six months prior to data collection. After Institutional Research Board approval (Appendix 1A), informed consent was given by subjects prior to the study. Finally, subjects’ descriptive data (date of birth, race, gender, height, weight, years of experience, and dominant limb), resting heart rate, and heart rate maximum were gathered or measured.

INSTRUMENTS

Accelerometer. As previously mentioned, accelerometers can record raw acceleration of a limb or the trunk to measure energy expended (Kang, 2008). A triaxial accelerometer (ActiGraph GT9X Link) equipped with a gyroscope and magnetometer was used (ActiGraph, 2016a). This brand was chosen due to its portability, capacity to detect acceleration in three planes, inexpensiveness, and its validity and reliability (Kelly et al., 2013; McClain et al., 2007). ActiGraph GT9X Link can also measure heart rate with the addition of a heart rate sensor with bluetooth technology (ActiGraph, 2016a). Finally, ActiGraph GT9X Link can record raw acceleration and number of steps, to be analyzed with the ActiLife software and be converted to MET, kilocalories, physical activity intensity and activity bouts (ActiGraph, 2016a).

ActiLife. ActiLife is a data analysis software created by ActiGraph (2016b). ActiLife (version 6.13.3) has a series of validated algorithms to measure energy expenditure for certain populations (e.g., Sasaki, John, and Freedson, 2011). Within the study, ActiLife was used to analyze heart rate, acceleration, and activity bouts.

Cove Moulding. A red cove moulding of 1.75 centimeters (width) x 1.75 centimeters (thickness) and 6.096 meters (20 feet) length was used to add a "tin" of 1 inch and/or 2 inches high, which according to the World Squash Federation (2013), "… is the area of the front wall covering the full width of the court and extending from the floor up to and including the lowest horizontal line" (p. 11). In other words, a tin of one or two inches high (depending on the situation) was added at the bottom of the front wall covering its 20-foot width. The aim of the tin was to modify the rule that allows the ball to touch any part of the front wall to prohibit winning a rally if the ball touched the tin under any circumstance (Figure 1).

Equations. ActiLife software has different validated equations for transforming raw acceleration data into physical activity energy expenditure (kilocalories and MET) and activity bouts. To know the kilocalories expended during a racquetball game the

"Freedson VM3 combined" equation was used as explained elsewhere (Actigraph, 2016c). For converting acceleration into METs of racquetball the Crouter adult 2010 equation was used (Actigraph, 2016d). This equation was chosen because it is the only one that is based on a study that measured racquetball among other activities (Crouter, Kuffel, Haas, Frongillo, & Bassett Jr, 2010). Cut points, to distinguish among different intensities of exercise, were established according to the "Freedson adult VM3 2011" cut points (Actigraph, 2016e) and based on the Sasaki and colleagues (2011) study. To know the heart rate maximum of each participant, the age predicted maximal heart rate equation (220 – age of subject) was used (Baechle & Earle, 2008). Heart rate reserve (HRR) was obtained by measuring the heart rate maximum (HR_{max}) and resting heart rate (HR_{rest}) and applying the following formula: $HRR= HR_{max}-HR_{rest}$. In addition, by using HRR, the heart rate percentage of each participant could be found with the Karvonen formula (Karvonen, Kentala, & Mustala, 1957).

Heart Rate Sensor. A Polar H6 heart rate sensor was used to show heart rate during activity with the ActiGraph GT9X Link and to measure resting heart rate while using the "Polar Beat" software app for smartphones. The Polar H6 heart rate sensor is a strap that connects via bluetooth with training devices or, in this case, with the ActiGraph model chosen for this research.

Polar Beat. Polar beat is a free application created by Polar and available for smartphones. The application can be linked via bluetooth with a Polar H6 heart rate sensor to measure the heart rate of a subject while performing each activity or even while resting. Polar beat was used to help measure resting heart rate while laying down as explained in "How to Measure your resting heart rate" (Polar Electro Inc., 2016).

Scale/Stadiometer. A scale with stadiometer (Detecto 439) was used to measure the weight and height of each participant. Data obtained through the Detecto 439 was used to initialize the Actigraph GT9X and describe the population's average weight and height.

SPSS statistics. SPSS is software used to analyze and test all data collected. For this study, it was used to analyze data through chi-square tests and to know the "adjusted standardized residual" of any significant variables.

Timer. A digital stopwatch (Adanac 3000-ST083000) was used to measure each game length per match.

Video recorder. A GoPro Hero 3+ attached to the back wall was used to record each game/match to later quantify the number of hits per rally while playing in each one of the randomized conditions.

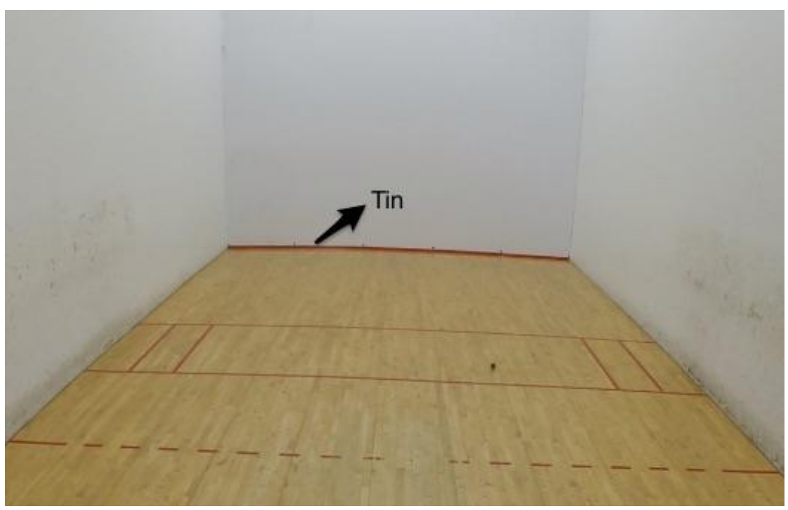

Figure 1: Photograph of a tin

PROCEDURE

Following institutional ethics approval, participants were recruited by e-mail and asked to participate in a tournament over two days. To participate in the study, participants completed a consent form and provided basic demographic data. Participants weight (lbs.) and height (in.) were measured with a scale-stadiometer to be used later while initializing the ActiGraph GT9X Link. Resting heart rate was measured as explained in “How to measure your resting heart rate” (Polar Electro Inc., 2016).

Prior participants playing racquetball each accelerometer was initialized with all the demographic data previously given by them. In addition, each Actigraph GT9X Link was set up at a sampling rate of 70 Hz. This decision was taken because as previously described by other authors, accelerometers’ sampling rate depends on the length of time to be used and the type of physical activity (Bonomi, 2010; Khan, Hammerla, Mellor, & Plöz, 2016; Sasaki, da Silva, da Costa, & John, 2016).

After initializing each accelerometer, ActiGraph GT9X Link and heart rate sensor were worn as specified by the owner’s manual (on the non-dominant wrist and chest). While wearing the accelerometer and heart rate sensor participants played a mini-tournament to know the influence of the modification of the rule (addition of a tin) on energy expenditure, heart rate percentage, MVPA%, and hits per rally. During the mini-tournament, three random conditions per session (two sessions) were performed each day: a match without tin, a match with a one-inch tin, and a match with a two-inch tin were played each day. Each match consisted of three games up to 11 points designated to each one. The winning player for each game was awarded three tournament points and the one that won a match earned seven tournament points. In total a maximum of 49 points was possible each match. This format is often used during domestic tournaments, as it ensures that players continue to put forth effort even if unlikely to win the match, as they may make up the difference in the next match or game.

Time per game was measured with a stopwatch at the beginning and end of each game. Each match was recorded with a GoPro Hero3+ attached to the back wall of the court, and analyzed later to assess the number of hits per rally. All data obtained through Actigraph GT9X Link was processed through ActiLife (ActiGraph, 2016b) with the previously mentioned equations for converting acceleration to kilocalories, METs/minute, and time expended on moderate to vigorous physical activity.

DATA ANALYSIS

After collecting data, each accelerometer's data (m/s/s) was downloaded at 10 seconds epochs to be used with the Crouter equation (2010) to calculate MET/minute, per manufacturer instructions (Actigraph 2016d). Heart rate data gathered by the accelerometer was downloaded and converted into an Excel file to analyze heart rate values. Each heart rate value was reported in the spreadsheet every 10 seconds. Although most of the heart rate data was collected, some 10 seconds' information regarding heart rate was not recorded by the accelerometer. To avoid any misleading information, it was decided to consider only each range of 10 seconds that measured the heart rate, during each game, to obtain the average value of the heart rate for each player and game.

In regards to MET/min, kcal/min, and MVPA percentage, each of the equations, previously explained ("Crourer adult 2010", "Freedson VM3 combined", and "Freedson adult VM3 2011"), were used to calculate the average values for each measure, respectively. Moreover, to have reliable and accurate values, only complete minutes during each game were considered to convert raw acceleration to MET/min, kcal/min, and MVPA percentage.

Lastly, to know the number of hits per rally the video (GoPro Hero3+) was analyzed. Considering the definition of rally (previously mentioned), only the successful hits after the serve were considered.

All dependent variables used for analyses were average time, kcal/min, MET/min, HRR%, hits per rally, and MVPA% of time, for each game played by condition (each match had three games). Later, data was classified into three different groups (lower, normal, upper). To group each value, the lowest and highest values per measurement were established as the lower and higher limits. By knowing the lower and higher limits of the data, a range value was established and divided by three (e.g., the lowest value was 6.1 kcal/min and the highest value was 6.68 kcal/min; there was a difference of 0.58 kcal/min between the lowest and the highest values; this value was divided by three). Once each value was grouped, the frequency of occurrence of each group-value and condition was calculated for each condition (1-inch tin, 2-inch tin, no tin). The frequencies of the occurrence were analyzed with a two-way chi-square test per condition (two-way chi-square test). A two-way chi-square test was chosen due to the sample size, convenience of sample, and the classification value of the data (Hall & Getchell, 2014).

As previously mentioned, a two-way chi-square test was used to determine if a significant difference was among energy expenditure (METs and Kcal per minute), average heart rate percentage, hits per rally, and time playing from moderate to vigorous physical activity for the given conditions (match without tin, match with one-inch tin, match with two-inch tin) during racquetball game. The level of significance was established as .05 (p = .05). If a variable being measured was found significant an “adjusted standardized residual” test was performed to know where the significant value lay.

Lastly, descriptive data for each condition was calculated using the groups means for MET/min, kcal/minute, HRR%, percentage of time playing in MVPA zone, match length, game length, and hits per rally.

CHAPTER IV

FINDINGS

RESULTS

Descriptive data of the participants are shown in Table 1. In addition, the average values of kcal/min, MET/min, match length, game length, hits per rally, percentage of MVPA time relative to total time played, and percentage of heart rate per condition are shown in Table 2.

Table 1.

Demographic data of players

	Participant 1	Participant 2	Mean	Standard Deviation
Age[a]	47	51	49	2.83
Weight[b]	86.64	85.77	86.21	.62
Height[c]	1.68	1.76	1.72	.06
RHR[d]	66	60	63	4.24
HR_{max}	173	169	171	2.83
Years of experience	37	36	36.5	.71

Note. RHR = resting heart rate, HR_{max} = heart rate maximum

[a] years, [b] kilograms, [c] meters, [d] beats per minute

Table 2.

Average values (Mean ± SD) per condition and session

	Session 1			Session 2			Combined		
	NT	1-T	2-T	NT	1-T	2-T	NT	1-T	2-T
Physiological data									
Kcal/min	6.45±.1	6.50±.04	6.54±.08	6.49±.06	6.36±.16	6.38±.14	6.47±.08	6.43±.14	6.46±.14
MET/min	8.20±.22	8.18±.05	8.52±.31	8.32±.18	8.20±.34	8.07±.26	8.26±.2	8.19±.23	8.29±.36
HR%	83±8	83±10	81±10	75±9	80±8	75±10	79±9	82±9	78±10
MVPA%	98.96±2	99.41±1	99.44±1	98.91±1	96.48±4	97.62±4	98.93±1	97.94±3	98.53±3
Match data									
Match length[a]	39.48	44.05	23.78	30.59	48.94	35.99	34.94±6.29	46.5±9.52	29.85±8.63
Game length[a]	13.16±2.59	14.68±6.06	7.93±4	10.2±2.97	16.31±1.74	12±3.41	11.68±2.97	15.5±4.09	9.96±4
Hits per rally	2.61±1.55	3.36±2.61	3.34±2.41	2.89±1.8	3.76±2.6	3.28±2.5	2.73±1.66	3.55±2.84	3.31±2.45
Hits	269	360	194	211	333	256	480	693	450
Rallies	103	107	58	73	93	78	176	200	136
Skips	14	10	7	7	13	10	21	23	17
Hit-skip ratio	19.21:1	36:1	27.71:1	30.14:1	25.62:1	25.60:1	22.86:1	30.13:1	26.47:1

Notes. Hits, rallies, and skips are presented as a total, the other variables are presented as the mean value, NT = no tin, 1-T = 1-inch tin, 2-T = 2-inch tin

[a] time in minutes

After knowing the average values (per player and game) of MET/min, kcal/min, HR%, MVPA% time, and the number of hits per rally, each variable was grouped by frequency of occurrence and per condition (see Figures 2 to 6) as previously explained, to later be tested with the two-way chi-square test.

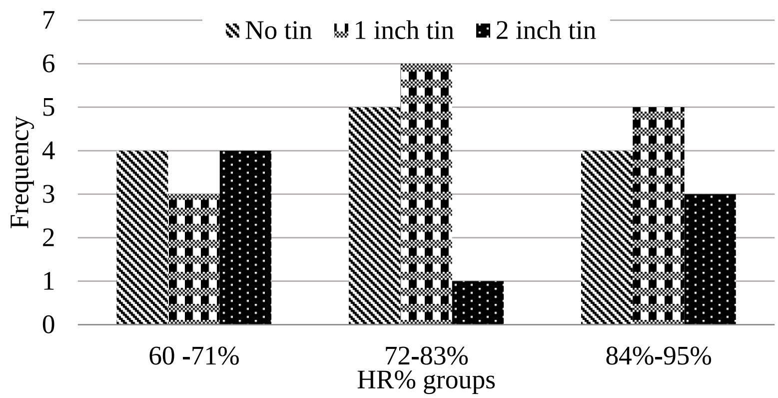

Figure 2: Frequency of occurrence of heart rate percentage per condition

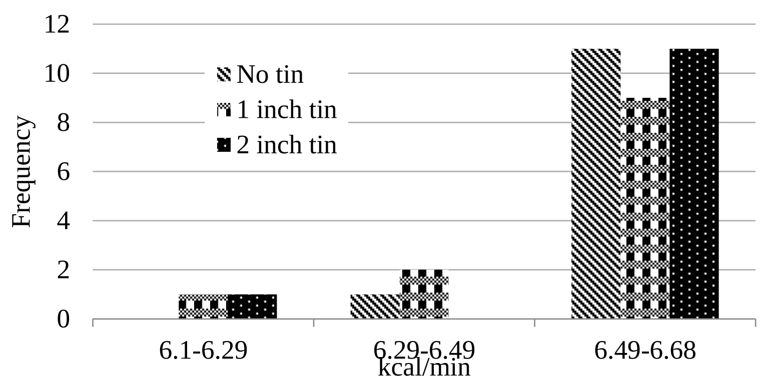

Figure 3: Frequency of occurrence of kilocalories per minute per condition during the games

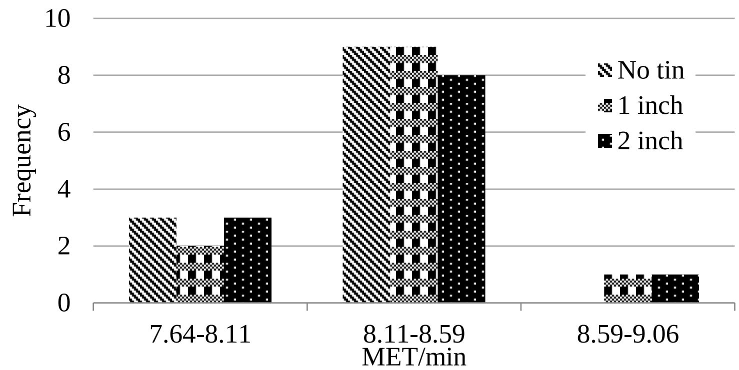

Figure 4: Frequency of occurrence of metabolic equivalents of task per minute per condition during the games

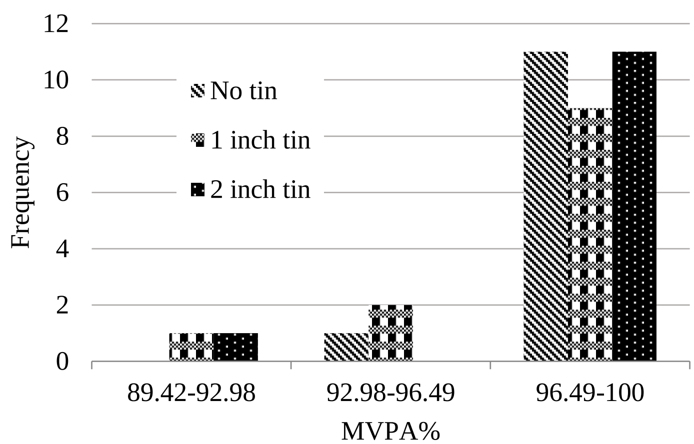

Figure 5: Frequency of occurrence of moderate to vigorous physical activity percentage per condition during the games

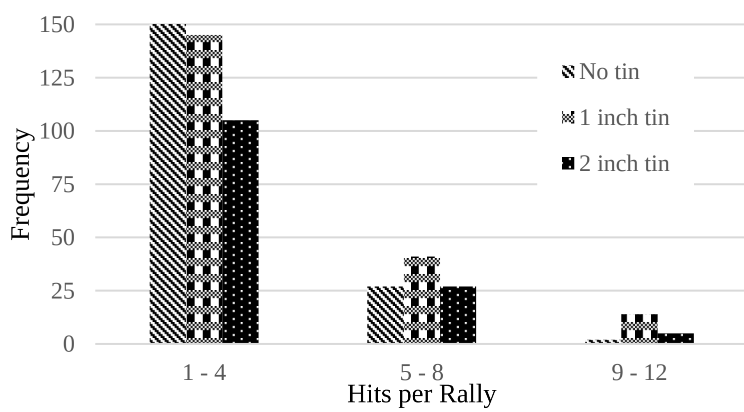

Figure 6: Frequency of occurrence of the number of hits per condition during the games

Multiple two-way chi-square tests were performed to determine whether a change of rule (addition of a tin) changed each of the dependent variables being measured while comparing them with a regular game (no change of rule). Differences among the conditions (no tin, 1-inch tin, 2-inch tin) were not significant for four of the variables being measured; average kilocalories per minute, X^2 (4, N = 36) = 3.26, $p > .05$; average metabolic equivalents of task per minute, X^2 (4, N = 36) = 1.33, $p > .05$; percentage of time performing moderate to vigorous physical activity, X^2 (4, N = 36) = 3.26, $p > .05$; and average heart rate percentage, X^2 (4, N = 36) = 1.42, $p > .05$, were not different among the conditions. Contrary to the other four variables, hits per rally were found to be significantly different, X^2 (4, N = 519) = 11.81, $p < .05$.

Based on the results of the two-way chi-square the following null hypotheses were accepted:

1. Energy expenditure is not different with a rule modification.
2. Average heart rate percentage is not different with a rule modification.
3. MVPA percentage time is not different with a rule modification.

Based on the results of the two-way chi square the following null hypothesis is rejected:

1. Hits per rally are not different with a rule modification.

Lastly, to know how far the observed frequencies were from the expected frequencies according to the two-way chi-square, an “adjusted standardized test” through SPSS was conducted. The results showed that for the range of 1 to 4 hits per rally the conditions of no tin (2.6) and 1-inch tin (-2.2) were significantly different than the expected frequency. Moreover, the values of no tin (-2.5) and 1-inch tin (2.7) were significantly different for the range of 9-12 number of hits while comparing the observed with the expected frequency. In other words, it might be predicted that the addition of a 1-inch tin will increase the number of hits per rally because it was observed a higher frequency of rallies ranging from 9-12 hits (observed = 14, expected = 8.1) and a decrease on the frequency of rallies ranging from 1-4 hits (observed = 145, expected = 155.3). Contrary to the addition of a 1-inch tin, it might be predicted that playing without a tin will decrease the frequency of rallies ranging from 9-12 hits (observed = 2, expected = 7.4) and increase the frequency of rallies ranging from 1-4 hits (observed = 153, expected = 141.3).

CHAPTER 5

DISCUSSION

The purpose of this study was to determine how rule modifications might influence energy expenditure (kcal/min and MET/min), heart rate percentage, MVPA% time, and number of hits per rally while playing. For this purpose, two amateur players of an "Open Skill" played a mini-tournament of six matches while wearing an accelerometer.

The author found in this study that no difference among four of the dependent variables being measured. MET/min, kcal/min, MVPA%, and HRR% were not different while comparing the three conditions (no tin, 1-inch tin, 2-inch tin). The only difference found among the variables was for the number of hits per rally while comparing them among the three conditions. Specifically, there was a significant difference on hits per rally while comparing those matches played with a 1-inch tin with those played without a tin.

Physiological Measurements

The findings show that while playing without the proposed change of rule (no tin) the average expenditure of kcal/min was 6.47. This value is different from those found in other studies. Berg and colleagues (2007) found that on average during a racquetball game the energy expended is 11.1 kcal/min. Almost similar to the findings of Berg and colleagues, Montpetit et al. (1987) reported an average of 10 kcal/min expended while playing racquetball. The difference of each value found by the authors may be due to the different instruments and methodology used; while Berg et al. (2007) and Montpetit et al. (1987) measured VO_2 to gather data regarding energy expenditure (kcal/min), this study was performed by using an accelerometer to measure raw acceleration to estimate kilocalories per minute. Moreover, kilocalories may be influenced by a participant's age (Kang, 2008), which may be linked to a lower resting metabolic rate (Elia, Ritz, & Stubbs, 2000) and activity energy expenditure (Johannsen et al., 2008; Manini, 2010); while mean age of participants within this study was 49 years, for the previously mentioned studies, participant's mean age was 23 and 27 years.

MET values have been reported by other authors (e.g., Ainsworth et al., 2011a [10 MET]; Taylor et al., 1987 [7 MET]. This study found a value of 8.26 MET/minute while playing racquetball (no rule change). Differences among the studies may be due to differences of skill among participants or estimations that may be based in similar sports (Ainsworth et al., 2011b), while the value found by Taylor et al (1987) is for recreational racquetball players and the estimated value of performing competitive racquetball is 10 MET (Ainsworth et al., 2011a). Subjects within this study were of an "open skill level", which is the highest amateur level. In addition, as previously mentioned, energy expenditure (kilocalories and MET) may be influenced by aging.

In this study, the average heart rate percentage of the participants was 79%, compared with 87% found by Montgomery (1981) and 83% by Morgans and colleagues

(1984). Differences in the values may be due to disparities among those playing, as shown by Montgomery (1981). Montgomery (1981) found that while playing a lower level (90% HR) versus a higher level player (70%) the heart rate percentage had a tendency to decrease or increase depending on the player. This value is within the range of the heart rate percentage reported. Interestingly, within this study the average resting heart rate per player had a difference of almost ±12%, even though the participants were of the same skill level.

Regarding percentage of time expended on moderate to vigorous physical activity (MVPA), it was found in this study that almost 99% of the time players were within this zone. This seems to be the first study to describe the quantity of time (expressed as a percentage) expended on the MVPA zone. Although, this is a novel finding, results may be influenced by the structure of the mini-tournament, which did not allow time-outs and awarded points for winning a game (3 points) and a match (7 points), in addition, all the matches were streamed, in conjunction all the previously mentioned motives may helped to motivate participants to give their best at every moment.

Match Measurements

While playing without the rule change the average number of hits per rally (2.73) was significantly different than the number of hits when the rule was changed (1-inch tin [3.55] and 2-inch tin [3.31]). The number of hits may be different because the modification of the rule obligated the players to hit the front wall a little higher than a normal match (no tin). Maybe, they were used to playing and winning the points by hitting the ball to bounce on the bottom part of the front wall in such a way that the opponent could not hit the ball.

Match length (35min.) reported within this study, was not analyzed for significant differences among the conditions because of the structure of each match and the insufficient number of matches (two) per condition. For instance, three games per match were played (even if one player won the first two games) and each game was played to 11 points while the IRF rulebook (2014) clearly specifies that the first two games have to be played to 15 points and in case of a tie score then a tie-breaker is played to 11 points (IRF, 2014). A comparison among the different studies seem to be unrealistic because each match per study was performed different. For example, Montgomery's (1981) and Pipes' (1979) matches performed two games to 21 points and a tie-breaker of 11 points in case of a draw. Moreover, the rule has changed and, as previously mentioned, now each game is to 15 points. Despite changes of the rules, the findings of this study agreed with the findings Montgomery (1981) who mentioned that a match lasted 35 to 50 minutes, depending on the skill level of the players. Findings of this study should be taken with caution since they may not reflect the number of games and points played during an official match.

The change of the rule (addition of a tin) was not significant for four of the variables being measured. The only difference was found for the number of hits per rally while comparing a regular match (no tin) with a 1-inch tin match. Nevertheless, it is important to note that the 1-inch condition, compared to a match without tin, increased the match length to almost 12 minutes. Although, a match with the addition of a 1-inch tin may not be statistically different with regards to energy expenditure (kcal/min and MET/min), HR percentage, and MVPA percentage, the increment in number of hits per rally and time may help to increase the total energy expended and MVPA time, which could result in a more interesting and healthier sport because more hits and time are expended.

Finally, this study supports the idea that racquetball is a healthy physical activity. Specifically, an average match may last at least 30 minutes which is the daily amount of MVPA time recommended by ACSM (2013). In addition, it also supports the idea that if played 3-5 days a week for a minimum of 30 minutes, a range of 743-1239 MET a week or 582-970 kcals may be expended during a week.

LIMITATIONS AND FUTURE STUDIES

Racquetball may be a healthy way to engage on moderate to vigorous physical activity as found by this study. Nevertheless, some cautions should be taken. For instance, the findings in this study cannot be generalized due to the number of participants and their skill level, which may not be found among those who play racquetball recreationally.

As previously mentioned, ActiGraph accelerometers are widely used among the scientific community, probably because of their portability, capacity to detect movement, intensity, duration, frequency (Kang, 2008), their good correlation with VO_2 (r = .81 – .88, $p < .001$) (Kelly et al., 2013), and reliability while measuring moderate to vigorous physical activity (McClain, Sisson, & Tudor-Locke, 2007). However, accelerometers have also been questioned. Lyden, Kozey, Staudenmeyer, and Freedson (2011) evaluated the validity of eleven energy expenditure prediction equations used by three different accelerometers. Generally, they found that all the equations underestimated energy expenditure including activities of daily living and treadmill activities (underestimated or overestimated depending on the equation), This may explain why a lower value of kcal/min was found in this study.

Sasaki and colleagues (2016) say that even though acceleration has a strong relationship with energy expenditure, the location (e.g., where it is worn) of the accelerometer may influence its ability to detect physical activity. Moreover, the equations being used in this study are based on studies that measured energy expenditure by using an accelerometer on the hip and not on the wrist (e.g., Crourer et al., 2010; Sasaki et al., 2011).

Lastly, there is a lack of information regarding the accuracy and reliability of the ActiGraph GT9X. Most of the studies have compared the reliability of previously released models (e.g. Kelly et al., 2013) and few studies have measured the validity of the previously mentioned accelerometer focused on its ability to measure sleeping values (e.g., Lee & Suen, 2016).

Future studies should focus on measuring the energy expended while playing racquetball with another instrument. For instance, it will be interesting to measure energy expenditure of racquetball matches with an instrument able to combine heart rate and acceleration in a single equation (e.g., Actiheart).

A significant difference was found for the number of hits per rally across conditions. Considering the results, it would be interesting to replicate this study with more participants and different populations. For example, a study with professional players might find that the proposed rule modification changes the game in such a way that energy expenditure, average heart rate, and moderate to vigorous physical activity increase. Furthermore, research distinguishing the amount of time a player engages in moderate or vigorous physical activity (not combining them) might be necessary.

In conclusion, this study supports and enforces the idea that racquetball is a healthy sport. Specifically, while playing racquetball it can be expected that most of the time the participants will be performing a moderate to vigorous physical activity with an energy expenditure of 6.47 kcal/min or 8.26 MET/min and a match length of at least 30 minutes. Even though rule modifications may not significantly increase the amount of energy expended and the heart rate, it may help to increase the amount of time per match and the number of hits per rally (for the 1-inch tin condition) which by transfer makes the game even healthier.

REFERENCES

ActiGraph. (2016a). *ActiGraph GT9X Link.* Retrieved from: http://actigraphcorp.com/products-showcase/activity-monitors/actigraph-link/

ActiGraph. (2016b). *Powerful data analysis platform.* Retrieved from: http://actigraphcorp.com/products-showcase/software/actilife/

ActiGraph. (2016c). *What is the difference among the energy expenditure algorithms?* Retrieved from https://actigraph.desk.com/customer/portal/articles/2515835

ActiGraph. (2016d). *What is the difference among MET algorithms?* Retrieved from https://actigraph.desk.com/customer/portal/articles/2515804

ActiGraph. (2016e). *What's the difference among the cut points available in actilife?* Retrieved from https://actigraph.desk.com/customer/en/portal/articles/2515803-what-s-the-difference-among-the-cut-points-available-in-actilife-

Ainsworth, B., Haskell, W., Herrmann, S., Meckes, N., Bassett, J. D., Tudor-Locke, C., . . . Leon, A. (2011a). *The compedium of physical activities tracking guide.* Retrieved from https://sites.google.com/site/compendiumofphysicalactivities/home

Ainsworth, B. E., Haskell, W. L., Herrmann, S. D., Meckes, N., Bassett Jr, D. R., Tudor-Locke, C., ... & Leon, A. S. (2011b). 2011 Compendium of physical activities: A second update of codes and MET values. *Medicine and Science in Sports and Exercise*, *43*(8), 1575-1581.

American College of Sports Medicine [ACSM]. (2013). *ACSM's guidelines for exercise testing and prescription*: Lippincott Williams & Wilkins.

American Hearth Association [AHA]. (2016). *American heart association recommendations for physical activity in adults.* Retrieved from: http://www.heart.org/HEARTORG/HealthyLiving/PhysicalActivity/FitnessBasics/American-Heart-Association-Recommendations-for-Physical-Activity-in-Adults_UCM_307976_Article.jsp#.WCU1PTI-KRs

Arias, J. L., Argudo, F. M., & Alonso, J. I. (2011). Review of rule modification in sport. *Journal of Sports Science and Medicine*, *10*(1), 1-8.

Baechle, T. R., & Earle, R. W. (2008). *Essentials of strength training and conditioning* (3rd ed.). Champaign, IL: Human Kinetics.

Bartoli, W. P., Slentz, C. A., Murdoch, S., Pate, R., Davis, J., & Durstine, J. (1994). Effects of a 12-week racquetball program on maximal oxygen consumption, body composition and blood lipoproteins. *Research in Sports Medicine: An International Journal*, *5*(2), 157-164.

Berg, K., Narazaki, K., Latin, R., Vincent, W., Meisinger, M., Sjoberg, C., & Kaufman, C. (2007). Oxygen cost and energy expenditure of racquetball. *Journal of Sports Medicine and Physical Fitness, 47*(4), 395-400.

Bombelli, M., Facchetti, R., Sega, R., Carugo, S., Fodri, D., Brambilla, G., . . . Mancia, G. (2011). Impact of body mass index and waist circumference on the long-term risk of diabetes mellitus, hypertension, and cardiac organ damage. *Hypertension, 58*(6), 1029-1035.

Borrell, L. N., & Samuel, L. (2014). Body mass index categories and mortality risk in US adults: The effect of overweight and obesity on advancing death. *American Journal of Public Health*, *104*(3), 512-519.

Bonomi, A. G. (2010). Physical activity recognition using a wearable accelerometer. *Sensing Emotions*, *12*, 41-51.

Brookreston, N. (2015, July 16) *Using heart rate monitoring for personal training.* Retrieved from http://certification.acsm.org/blog/2015/july/using-heart-rate-monitoring-for-personal-training

Centers for Disease Control and Prevention (CDC). (2012, April 21, 2012). *Overweight & obesity: Defining adult overweight and obesity.* Retrieved from http://www.cdc.gov/ obesity/adult/defining.html

Centers for Disease Control and Prevention (CDC). (2015a, September 21, 2015). *Overweight & obesity: Adult obesity facts*. Retrieved from http://www.cdc.gov/obesity/data/adult.html

Centers for Disease Control and Prevention [CDC]. (2015b). *Nutrition, physical activity and obesity: data, trends and maps.* Retrieved from https://nccd.cdc.gov/ NPAO_DTM/IndicatorSummary.aspx?category=71&indicator=32&year=2013&yearId=17

Centers for Disease Control and Prevention [CDC]. (2015c). *Glossary of terms.* Retrieved from http://www.cdc.gov/physicalactivity/basics/ glossary/index.htm#aerobic

Crouter, S. E., Kuffel, E., Haas, J. D., Frongillo, E. A., & Bassett Jr, D. R. (2010). A refined 2-regression model for the actigraph accelerometer. *Medicine and Science in Sports and Exercise*, *42*(5), 1029-1037.

Coupet, A., & Gerville-Réache, L. (2007). Comparison between table tennis scoring systems (11 and 21 points) by probabilistic simulation. *People's Sports Publishing House of China*, 33-40.

Dishman, R. K. (1988). Exercise adherence research: Future directions. *American Journal of Health Promotion*, *3*(1), 52-56.

Elia, M., Ritz, P., & Stubbs, R. J. (2000). Total energy expenditure in the elderly. *European Journal of Clinical Nutrition*, *54*, S92-103.

Grahame, A. (n.d.). *The new badminton rules*. Retrieved from http://www.livestrong.com/article/144589-the-new-badminton-rules/

Hall, S., & Getchell, N. (2014). *Research methods in kinesiology and the health sciences.* Philadelphia, PA: Lippincott Williams & Wilkins.

Hänggi, J. M., Phillips, L. R., & Rowlands, A. V. (2013). Validation of the GT3X ActiGraph in children and comparison with the GT1M ActiGraph. *Journal of Science and Medicine in Sport*, *16*(1), 40-44.

Hawk-Eye innovations. (n.d.). *Tennis.* Retrieved from http://www.hawkeyeinnovations.co.uk/sports/tennis

International Racquetball Federation [IRF]. (2014). *Official rules of racquetball*. Retrieved from http://www.internationalracquetball.com/uploads/2/5/2/6/2526352/irf_rulebook.pdf

International Racquetball Federation [IRF]. (n.d.-a). *About racquetball.* Retrieved from http://www.internationalracquetball.com/about-racquetball.html

International Racquetball Federation [IRF]. (n.d.-b). *IRF history.* Retrieved from http://www.internationalracquetball.com/irf-history.html

International Tennis Federation [ITF]. (2016a). *History.* Retrieved from http://www.itftennis.com/about/organisation/history.aspx

International Tennis Federation [ITF]. (2016b). *History*. Retrieved from http://www.itftennis.com/technical/balls/other/history.aspx

Johannsen, D. L., DeLany, J. P., Frisard, M. I., Welsch, M. A., Rowley, C. K., Fang, X., ... & Ravussin, E. (2008). Physical activity in aging: Comparison among young, aged, and nonagenarian individuals. *Journal of Applied Physiology*, *105*(2), 495-501.

Johnson, N. B., Hayes, L. D., Brown, K., Hoo, E. C., & Ethier, K. A. (2014). CDC national health report: Leading causes of morbidity and mortality and associated behavioral risk and protective factors—United States, 2005–2013. *Morbidity and Mortality Week Report*, *63*(4), 3-27.

Kang, J. (2008). *Bioenergetics primer for exercise science*. Champaign, IL: Human Kinetics.

Karvonen, M., Kentala, K., & Mustala, O. (1957). The effects of training heart rate: a longitudinal study. *Annales Medicinae Expperimentalis et Biologiae Fenniae, 35*, 307-315

Kelly, L. A., McMillan, D. G., Anderson, A., Fippinger, M., Fillerup, G., & Rider, J. (2013). Validity of actigraphs uniaxial and triaxial accelerometers for assessment of physical activity in adults in laboratory conditions. *BMC Medical Physics*, *13*(1), 1-7.

Khan, A., Hammerla, N., Mellor, S., & Plötz, T. (2016). Optimising sampling rates for accelerometer-based human activity recognition. *Pattern Recognition Letters*, *73*, 33-40.

Lee, P. H., Macfarlane, D. J., Lam, T., & Stewart, S. M. (2011). Validity of the international physical activity questionnaire short form (IPAQ-SF): A systematic review. *International Journal of Behavioral Nutrition and Physical Activity*, *8*(1), 115.

Lee, P. H., & Suen, L. K. (2016). The convergent validity of Actiwatch 2 and ActiGraph Link accelerometers in measuring total sleeping period, wake after sleep onset, and sleep efficiency in free-living condition. *Sleep and Breathing*, 1-7. doi:10.1007/s11325-016-1406-0

Lyden, K., Kozey, S. L., Staudenmeyer, J. W., & Freedson, P. S. (2011). A comprehensive evaluation of commonly used accelerometer energy expenditure and MET prediction equations. *European Journal of Applied Physiology*, *111*(2), 187-201.

Manini, T. M. (2010). Energy expenditure and aging. *Ageing Research Reviews*, *9*(1), 1-11.

McClain, J. J., Sisson, S. B., & Tudor-Locke, C. (2007). Actigraph accelerometer interinstrument reliability during free-living in adults. *Medicine and Science in Sports and Exercise*, *39*(9), 1509-1514.

Mifflin, M. D., St Jeor, S. T., Hill, L. A., Scott, B. J., Daugherty, S. A., & Koh, Y. O. (1990). A new predictive equation for resting energy expenditure in healthy individuals. *The American Journal of Clinical Nutrition*, *51*(2), 241-247.

Mohammed, M. H. H. (2013). Twelve weeks study of body composition and trunk flexibility between football and squash players from pre to post test. *Journal of Physical Education and Sport*, *13*(1), 88-90.

Montgomery, D. (1981). Heart rate response to racquetball. *The Physician and Sports Medicine, 9*(10), 59-62.

Montoye, H. J., Kemper, H. C., Saris, W. H., & Washburn, R. A. (1996). *Measuring physical activity and energy expenditure*: Champaign, IL: Human Kinetics.

Montpetit, R. R., Beauchamp, L., & Léger, L. (1987). Energy requirements of squash and racquetball. *Physician & Sports Medicine, 15*(8), 106.

Morgans, L. F., Scovil, J. A., & Bass, K. M. (1984). Heart rate responses during singles and doubles competition in racquetball. *Physician and Sports Medicine, 12*(11), 64-68.

Morgenstern, C. (1980). *Playing the racquets: the complete guide to the basics of tennis, squash, racquetball, paddle tennis, platform tennis, and one- and four-wall paddleball.* New York: New York: Dell Pub. Co.

National Heart, Lung, and Blood Institute [NHLBI]. (2013). *Managing overweight and obesity in adults: Systematic evidence review from the obesity expert panel.* Retrieved from: http://www.nhlbi.nih.gov/sites/www.nhlbi.nih.gov/files/obesity-evidence-review.pdf

Ng, M., Fleming, T., Robinson, M., Thomson, B., Graetz, N., Margono, C., . . . Gakidou, E. (2014). Global, regional, and national prevalence of overweight and obesity in children and adults during 1980–2013: A systematic analysis for the global burden of disease study 2013. *The Lancet, 384*(9945), 766-781.

Ogden, C. L., Carroll, M. D., Kit, B. K., & Flegal, K. M. (2014). Prevalence of childhood and adult obesity in the United States, 2011-2012. *The Journal of the American Medical Association, 311*(8), 806-814.

Percy, D. F. (2009). A mathematical analysis of badminton scoring systems. *Journal of the Operational Research Society, 60*(1), 63-71.

Phomsoupha, M., & Laffaye, G. (2015). The science of badminton: Game characteristics, anthropometry, physiology, visual fitness and biomechanics. *Sports Medicine, 45*(4), 473-495.

Physical Activity Guidelines Advisory Committee. (2008). Physical activity guidelines advisory committee report, 2008. *Washington, DC: US Department of Health and Human Services*.

Pipes, T. (1979). The racquetball pro: A physiological profile. *Physician and Sports Medicine, 7,* 91-94.

Pluim, B. M., Staal, J. B., Marks, B. L., Miller, S., & Miley, D. (2007). Health benefits of tennis. *British Journal of Sports Medicine*. *41*(11), 760-768.

Polar Electro Inc. (2016) *How to measure your resting heart rate*. Retrieved from https://www.polar.com/en/running/how-to-measure-resting-heart-rate

Robusto, K. M., & Trost, S. G. (2012). Comparison of three generations of ActiGraph™ activity monitors in children and adolescents. *Journal of Sports Sciences*, *30*(13), 1429-1435.

Rousset, S., Fardet, A., Lacomme, P., Normand, S., Montaurier, C., Boirie, Y., & Morio, B. (2015). Comparison of total energy expenditure assessed by two devices in controlled and free-living conditions. *European Journal of Sport Science*, *15*(5), 391-399.

Salmoni, A. W., Sidney, K., Michel, R., Hiser, J., & Langlotz, K. (1991). A descriptive analysis of elite-level racquetball. *Research Quarterly for Exercise and Sport,* *62*(1), 109-114.

Sasaki, J. E., John, D., & Freedson, P. S. (2011). Validation and comparison of ActiGraph activity monitors. *Journal of Science and Medicine in Sport*, *14*(5), 411-416.

Sasaki, J. E., da Silva, K. S., da Costa, B. G., & John, D. (2016). Measurement of physical activity using accelerometers. *Computer-Assisted and Web-Based Innovations in Psychology, Special Education, and Health*, 33.

Sylvis, J. (1985). *Racquetball for everyone: technique and strategy*. Englewood Cliffs, N.J.: Englewood Cliffs, N.J.: Prentice-Hall.

Taylor, H. L., Jacobs, D. R., Schucker, B., Knudsen, J., Leon, A. S., & Debacker, G. (1978). *Journal of Chronic Diseases*, *31*(12), 741-755.

Turner, E. T., & Hogan, M. (1988). *Skills & strategies for winning racquetball*. Champaign, Ill.: Champaign, Ill.: Leisure Press.

United States Olympic Committee [USOC]. (n.d.-a). *History of racquetball.* Retrieved from http://www.teamusa.org/usa-racquetball/about/history-of-racquetball

United States Olympic Committee [USOC]. (n.d.-b). *Mission & values.* Retrieved from http://www.teamusa.org/usa-racquetball/about/mission-and-values

United States Racquetball Museum. (2012). *Historical timeline.* Retrieved from http://www.racquetballmuseum.com/historicaltimeline.html

Verner, B. (1992). *Racquetball: basic skills and drills* (3rd ed.). Mountain View, Calif.: Mountain View, Calif.: Mayfield Pub. Co.

Welk, G. (2002). *Physical activity assessments for health-related research:* Human Kinetics.

World Cancer Research Fund, & American Institute for Cancer Research. (2007). *Food, nutrition, physical activity, and the prevention of cancer: A global perspective*. Retrieved from: http://discovery.ucl.ac.uk/4841/1/4841.pdf

World Squash Federation. (2013). *World squash singles rules 2014*. Retrieved from http://www.ussquash.com/wp-content/uploads/2014/03/131023_Rules-of-Singles-Squash-2014.pdf

Wright, M. (2014). OR analysis of sporting rules–A survey. *European Journal of Operational Research, 232*(1), 1-8.

APPENDICES

Appendix 1A

Oklahoma State University Institutional Review Board

Date:	Thursday, October 06, 2016
IRB Application No	ED16148
Proposal Title:	Influence of Racquetball Rule Modification on Energy Expenditure and Heart Rate in Amateur Players
Reviewed and Processed as:	Expedited

Status Recommended by Reviewer(s): Approved Protocol Expires: 10/5/2017

Principal Investigator(s):

Jesus Hernandez Sarabia	Timothy Baghurst
	189 Colvin Center
Stillwater, OK 74078	Stillwater, OK 74078

The IRB application referenced above has been approved. It is the judgment of the reviewers that the rights and welfare of individuals who may be asked to participate in this study will be respected, and that the research will be conducted in a manner consistent with the IRB requirements as outlined in section 45 CFR 46.

☐ The final versions of any printed recruitment, consent and assent documents bearing the IRB approval stamp are attached to this letter. These are the versions that must be used during the study.

As Principal Investigator, it is your responsibility to do the following:

1.Conduct this study exactly as it has been approved. Any modifications to the research protocol must be submitted with the appropriate signatures for IRB approval. Protocol modifications requiring approval may include changes to the title, PI advisor, funding status or sponsor, subject population composition or size, recruitment, inclusion/exclusion criteria, research site, research procedures and consent/assent process or forms
2.Submit a request for continuation if the study extends beyond the approval period. This continuation must receive IRB review and approval before the research can continue.
3.Report any adverse events to the IRB Chair promptly. Adverse events are those which are unanticipated and impact the subjects during the course of the research; and
4.Notify the IRB office in writing when your research project is complete.

Please note that approved protocols are subject to monitoring by the IRB and that the IRB office has the authority to inspect research records associated with this protocol at any time. If you have questions about the IRB procedures or need any assistance from the Board, please contact Dawnett Watkins 219 Scott Hall (phone: 405-744-5700, dawnett.watkins@okstate.edu).

Sincerely,

Hugh Crethar, Chair
Institutional Review Board

Appendix 2A

E-mail Recruitment

Dear, Mr._________

Researchers from the School of Applied Health & Educational Psychology pertaining to Oklahoma State University are looking for participants to complete a study called: "Influence of Racquetball Rule Modification on Energy Expenditure and Heart Rate in Amateur Players".

The aim of this study is to measure the energy expenditure and heart rate of amateur competitive racquetball players through acceleration and heart rate monitor. In addition, other aim of this study is to determine how rule modifications might influence energy expended and heart rate while playing.

To be able to reach our aim, we are looking for you to participate during two days in a mini-racquetball tournament in "Cushing Youth and Community Center" (700 South Little Avenue, Cushing, OK 74023). It is important to say that your participation is completely voluntary and you may decide not to participate with no penalty. In case you decide to participate, there is a financial aid for your transportation. For further details, please e-mail or call to:

Jesus Hernandez
Graduate Student
e-mail: jesusah@okstate.edu
phone number: (405) 269-4198

Timothy Baghurst, PhD
Associate Professor
e-mail: tim.baghurst@okstate.edu
phone number: (405) 744-4346

IRB Office
Approved: 10-06-2016
Expires: 10-05-2017
IRB#: ED-16-148

Appendix 3A

ADULT CONSENT FORM
OKLAHOMA STATE UNIVERSITY

INFUENCE OF RACQUETBALL RULE MODIFICATION ON ENERGY EXPENDITURE AND HEART REATE IN AMATEUR PLAYERS

INVESTIGATORS:

Jesus Alberto Hernandez Sarabia B.S.
Graduate Student, Health & Human Performance
Oklahoma State University

Timothy Baghurst, PhD
Coordinator, Physical Education and Coaching Science
Oklahoma State University

PURPOSE:

This study will measure the energy expenditure through acceleration, the heart rates of amateur competitive racquetball athletes, and will determine how rule modifications might influence energy expended and heart rate while playing. To measure the energy expenditure and heart rate while playing racquetball, three participants are needed to play a mini racquetball tournament while using accelerometers and a heart rate sensor, that is why your help is really important.

PROCEDURES

You will be asked to complete three sessions in the "Cushing Youth and Community Center" (700 South Little Avenue, Cushing, OK 74023) as follows:

- First session: In the morning your height, weight, and resting heart rate (lying down and relaxed during 5 minutes) will be measured. After completing those measures, you will be asked to provide information regarding your, date of birth, gender, race, dominant side (left or right), years of experience playing racquetball, and previous injuries during the last six months. After collecting the aforementioned data, you will proceed to play a mini-tournament, the details of which are outlined below. It is expected that this session will be three hours in length.
- Second and third session (tournament): In each session, you will be asked to wear an accelerometer and a heart rate sensor while playing. For your safety, protective glasses will be required. To know the influence of the modification of the rule (addition of a tin on the front wall of the court 1 or 2 inches above the floor) on the energy expenditure, heart rate, match length, and rally length, three randomized conditions (three mini tournaments) will be given: three matches without tin, three matches with a one-inch high tin, and three matches with a two-inch high tin. Each session will be two hours in length and will be recorded with a GoPro attached to the back wall of the court and an additional camera as a backup. It is expected that these sessions will be two hours in length.

- Because you are a competitive tournament player, we may stream your matches live through the internet depending on the quality of the internet connection. If quality is poor, the matches will be recorded and uploaded at a later point. The purpose of this is to encourage you to compete with the knowledge of having an audience watch you play, which is more similar to a tournament environment.

RISKS OF PARTICIPATION:

The risks associated with this research are the same as those encountered while exercising in a normal day. Although, exercise has benefits there are also related risks like:

- Sudden cardiac arrest or myocardial infarction.
- Injury(s)

In order to assist with the offset of these risks, A CPR trained person will be provided. If you experience any discomfort, please contact Jesús Alberto Hernández Sarabia or Dr. Timothy Baghurst

BENEFITS OF PARTICIPATION:

There are no direct benefits to you. However, you may gain an appreciation and understanding of how research is conducted. If you are interested, we will send you a copy of the results of the study when it is finished.

CONFIDENTIALITY:

The group of researchers will not ask any identifiable information about yourself. The records of this study will be kept private. Any written results will discuss group findings and will not include information that will identify you. Research records will be stored on a password protected hard drive in a locked office and only researchers and individuals responsible for research oversight will have access to the records.

Data will be destroyed three years after the study has been completed.

COMPENSATION:

Even though you may not be compensated directly, financial aid for your transportations will be available.

CONTACTS:

You may contact any of the researchers at the following addresses and phone numbers, should you desire to discuss your participation in the study and/or request information about the results of the study: Jesús Hernández, Graduate Student of Health and Human Performance, School of Applied Health & Educational Psychology Oklahoma State University, Stillwater, OK 74078, (405) 269-4198 or Timothy Baghurst, PhD, School of Applied Health & Educational Psychology Oklahoma State University, Stillwater, OK 74078, (405) 744-4346. If you have questions about your rights as a research volunteer, you may contact the IRB Office at 223 Scott Hall, Stillwater, OK 74078, 405-744-3377 or irb@okstate.edu

PARTICIPANT RIGHTS:

Your participation in this research is voluntary. There is no penalty for refusal to participate, and you are free to withdraw your consent and participation in this project at any time.

CONSENT DOCUMENTATION:

I herby give my permission to Jesús Hernandez-Sarabia and Timothy Baghurst, to use video taken of me for use in academic publications and presentations, as well as in any online videos of my matches, in which I might be identified. However, no personal information is provided in any of them. In addition, I have been fully informed about the procedures listed here. I am aware of what I will be asked to do and of the benefits of my participation. I also understand the following statements:

I affirm that I am 18 years of age or older.

I have read and fully understand this consent form. I sign it freely and voluntarily. A copy of this form will be given to me. I hereby give permission for my participation in this study.

______________________________ ____________________
Signature of Participant Date

I certify that I have personally explained this document before requesting that the participant sign it.

______________________________ ____________________
Signature of Researcher Date

IRB Office
Approved:
Expires:
IRB#:

VITA

Jesús Alberto Hernández Sarabia

Candidate for the Degree of

Master of Science

Thesis: INFLUENCE OF A RACQUETBALL RULE MODIFICATION ON ENERGY

EXPENDITURE AND HEART RATE IN AMATEUR PLAYERS

Major Field: Health and Human Performance

Biographical:

Education:

Completed the requirements for the Master of Science in Health and Human Performance at Oklahoma State University, Stillwater, Oklahoma in December 2016.

Completed the requirements for the Bachelor of Science in Physical Culture at Benemérita Universidad Autónoma de Puebla, H. Puebla de Zaragoza, Puebla in 2011.

Experience:

Graduate research assistant at Oklahoma State University.

Personal trainer in México

Physical Education professor

Professional Memberships:

Phi Kappa Phi chapter member at Oklahoma State University

National Strength and Conditioning Association