USING ELECTRONIC HANDGRIP DYNAMOMETRY TO DETERMINE HUMAN PERFORMANCE IN MASTER'S AGED CYCLISTS AND TRIATHLETES

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

DOCTOR OF PHILOSOPHY

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ABSTRACT

Purpose: This dissertation study sought to examine the correlations of maximal handgrip strength (HGS), rate of HGS force development, and HGS fatigability on lean body mass, peak power, functional threshold power, and aerobic capacity in master's aged cyclists and triathletes. **Methods**: A cross-sectional design was utilized and the analytic sample included n=31 master's aged cyclists and triathletes (age: 49.1±10.4 years). Achievement motivation was self-reported with a Situational Motivation Scale Questionnaire. A stationary bicycle trainer and metabolic cart was used to evaluate peak power and aerobic capacity with standardized protocols. Whole body bioelectrical impedance measured lean body mass. An electronic handgrip dynamometer examined maximal HGS, rate of HGS force development, and HGS fatigability. **Results**: Maximal HGS was moderately correlated with peak power ($r=0.46$; $p<0.01$), lean body mass was moderately correlated with peak power ($r=0.48$; $p<0.01$) and negligibly correlated with aerobic capacity ($r=0.37$; $p=0.04$). Rate of HGS force development was also moderately correlated with peak power ($r=0.36$; $p=0.04$). Maximal HGS was moderately correlated with rate of HGS force development ($r=0.63$; $p<0.01$). Moreover, after ranking the measures, maximal HGS was moderately correlated with peak power ($r=0.40$; $p=0.02$) and lean body mass was moderately correlated with peak power ($r=0.50$; $p<0.01$). **Conclusions**: The findings from this dissertation study suggests that maximal HGS and rate of HGS force development share a signal with peak power in master's aged cyclists and triathletes. Further, increased lean body mass is related to greater peak power. Maximal HGS and rate of HGS force development show promise for being utilized in a single protocol as a correlate for peak power when exhaustive testing is not possible, and maintaining lean mass is also advised for human performance in older endurance athletes.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF ABBREVIATIONS

ATP ....Adenosine Triphosphate.

CD-RISC...Connor Davidson Resilience Scale.

FTP...Functional Threshold Power.

GXT ....Graded Exercise Test.

HGS...Handgrip Strength.

HIIT...High Intensity Interval Training.

MVC ....Maximum Voluntary Contraction.

PPO ....Peak Power Output.

RFD...Rate of Force Development.

RPE ....Rating of Perceived Exertion.

U.S ....United States.

WAnT ....Wingate Anaerobic Power Test.

VO_2 Max ....Maximal Oxygen Consumption.

LIST OF APPENDIX TABLES

CHAPTER 1: INTRODUCTION

Triathlon consists of a swim, bike, and run leg in consecutive order. The swim commonly takes place in a lake or an ocean but has also been known to be completed in a pool or river. Then, athletes transition out of the water and onto a bicycle. During the bicycle leg, riders will choose a bike type (e.g., mountain, road, or time trial) that best suits the course profile. At the completion of the bicycle leg, athletes will thereafter transition to the run portion of the event. The run takes place on local roads, paths, or trails. Distances and terrain for each leg vary depending on the race.

In the year 1974, a local run club in San Diego, California began including swimming and cycling into their training group, and triathlon as a sport was created. The group consisted of amateur runners of all ages (Hunt, 2017; Kennedy, Knight, Falk Neto, Uzzell, & Szabo, 2020; Owens, Twist, Cobley, Howatson, & Close, 2019). The first triathlon in the United States (U.S.) was held at Mission's Bay in San Diego, California. A U.S. Naval officer from Hawaii, who was part of the local run club that kindled the triathlon, competed in this event, and eventually brought the sport to Hawaii. In 1979, the same Naval officer combined three of Hawaii's endurance events to create the 2.4-mile swim, 116-mile bike, and 26.2-mile run, which is now famously known as the Ironman distance triathlon. Today, this Hawaiian event serves as the Kona Ironman World Championships, which is one of the highest profile triathlon events (Club, Triathlon, Collins, & Magazine, 2010; Hunt, 2017).

Triathlon also has various distances for accommodating different types of athletes and levels. These options may include sprint and half Ironman distance. In the year 2000, the Olympic games added the Olympic triathlon distance event as an official sport. The Olympic distance triathlon consists of a 1500m swim, 40k bike, and 10k run, and is the most popular distance among amateur and professional triathletes. Interest and growth in triathlons increased rapidly after the triathlon was added as an official Olympic sport (Puccinelli et al., 2020). For example, total triathlon participation has now grown to over four million competitors worldwide (Kennedy et al., 2020). The growth in triathlon participation could be attributed to the diversity in sport (i.e., swimming, bicycling, running) and training.

Triathlon and cycling are physically compatible as a sport. The primary difference between the triathlon and cycling is that triathlon involves swimming and running. However, the bicycle training involved with triathlon is very similar, if not identical, to stand-alone bicycle training. The muscle recruitment, motor patterns, neural pathways, and energy systems are likewise reflective. Further, training metrics such as power are used interchangeably. The majority of physiology- and biomechanical-based research on cyclists involves triathletes as participants (Bini, Daly, & Kingsley, 2020; E. McGrath, Mahony, Fleming, & Donne, 2019; Redkva, Miyagi, Milioni, & Zagatto, 2018; Valenzuela & Lucia, 2018). As such, other factors related to the triathlon have evolved.

Bicycles are equipped with a derailer and gears, which were first introduced in the 1880's (Cox & Nauright, 2008; Mignot, 2016). Cycling culture and races began to populate into the 1890's, but issues with local police enforcement emerged because bike races overtook the roads and streets. However, as racing popularity increased, local newspapers were able to advertise races and the number of bicycles per 100 people in France, for example, elevated to over 30 by the year 1950 (Cox & Nauright, 2008). As the popularity of cycling grew, the health benefits of cycling similarly gathered attention. Cycling overall benefits physical and mental health (Oja et al., 2011). Thus, the health aspects from cycling could be important for lifespan athlete health.

Health Benefits of Triathlon and Cycling

Triathlon and cycling are types of physical activities that may preserve physical functioning, which is especially important during aging. Physical declines, such as decreased muscle function, are a normal part of aging that typically begin within the fourth decade of life. Specifically, adults between the ages of 40 and 50 years may lose more than 8% of muscle mass and strength relative to their early 30's (Wright, 2012). Given that age-related physical declines increase the risk for adverse health outcomes (Chen, Mears, & Hawkins, 2005), engaging in triathlon-related physical activities, especially earlier in life, may help to maintain muscle function during aging and mitigate subsequent disease and disability risk.

Triathlon-related physical activity participation may help in the prevention and treatment of certain types of morbidities. For example, a cross-sectional investigation of breast cancer survivors aged 48.0 ± 8.0 years evaluated the benefits of triathlon training in breast cancer survivors. The findings from this study suggests that triathlon training increased maximal aerobic capacity and peak isokinetic knee torque in breast cancer survivors, thereby indicating positive health benefits and anti-aging from triathlon exercise (Ng et al., 2017).

Triathlon training consists of a combination of swimming, biking, and running, which may each elicit multiple health benefits from diversity of training. Swimming requires upper body strength while also providing an aerobic benefit through non-weight bearing activities and is safe for bone and musculoskeletal health. Cycling includes lower body strength and aerobic benefits while also providing safety against connective tissue injuries. Running provides the chronic weight bearing affect needed to increase bone density and deliver aerobic benefits. Accordingly, the diversity in triathlon training may have health generalizability for non-athlete populations.

Practicing healthy behaviors earlier in life helps to maintain behavior adherence, and optimizes peaks in certain health factors that are influenced by age (Hawkins, Wiswell, & Marcell, 2003). As such, bicycling at a younger age may promote lifespan health carryover. For example, children who ride a bicycle to school experience greater physical fitness scores and higher cardiovascular fitness than their non-bicycle riding peers (Oja et al., 2011). Some studies have also reported that active transportation with a bicycle posits greater maximal aerobic power, musculoskeletal endurance, and overall greater fitness relative to walking in children (Kennedy et al., 2020; Oja et al., 2011). Therefore, cycling may present additional health benefits compared to walking as an active mode of transportation for children. While triathlon and cycling posit long-term physical health benefits, other non-physically driven attributes of health, such as mental health, may similarly improve.

Bicycling, as a form of transportation and social activity, also benefits mental health through leisure activity participation. Currently, only 6% of adults in North America make cycling related transportation commutes, while in some European countries, 25% of adults commute with a bicycle (Pelzer, 2010; Winters, Sims-Gould, Franke, & McKay, 2015). Further, infrastructure and a built environment that is conducive to active transportation improves health behaviors in older populations. The perception of bicycling may differ based on culture. Persons residing in the Netherlands and other European countries begin riding a bicycle at a young age. It is generally indigenous in such countries to use a bicycle as a standard for commuting to school, work, groceries, and physical enjoyment, which in turn, insinuates positive physical and mental health (Pelzer, 2010).

A universal similarity between countries, however, is the freedom experienced by being on a bicycle that other modes of transportation, such as a car, are unable to provide. Bicycling is a highly autonomous and self-controlling activity which makes it both intrinsically and extrinsically motivating for participation. A cross-sectional investigation of 1669 amateur cyclists and 1039 controls completed questionnaires to determine if differences existed in psychosocial health based on training volume. This study found that both high and low training volume led to increased psychosocial health. The investigation also found that higher volumes of training led to greater psychosocial health, suggesting that the time and dedication spent on training may not affect a person's mental well-being, but instead, could provide psychological enhancement due to training motivation (Oviedo-Caro et al., 2020). Likewise, autonomy and competence are pillars of the Self-Determination Theory, and engaging in activities that fulfill the pillars of Self-Determination Theory may improve physical activity adherence (Edmunds, Ntoumanis, & Duda, 2006).

Endurance training throughout adulthood is an important part of preventing physical declines (Hawkins et al., 2003). The master's athlete has been regarded as a model of successful aging that corroborates with greater physiological capabilities from being intrinsically motivated to continually participate in physical activity. This level of motivation creates a positive perspective on life from the years of training, which may also improve psychosocial health (Hawkins et al., 2003; Wooten et al., 2021). As the master's category in endurance sports continues growing, understanding the physiological, mechanical, and performance metrics of master's athletes will continue to increase performance and expand the field of master's endurance training.

Master's Athletes

The master category for triathlon and cycling begins at 35 years of age. A typical master's endurance athlete competes at the amateur level, works a full-time job, and has a family. Time management for master's athletes is especially important for proper training and recovery. Further, compared to most younger athletes, master's athletes are very limited on their training time due to family, work, and social responsibilities. While there are professional endurance athletes who still complete at the professional level, most master's athletes compete as an amateur. Therefore, training time may be limited to only a few hours a week (Sinisgalli et al., 2021). A well-planned training program can accommodate the unique lifestyle and physiological factors that may otherwise limit training in master's athletes.

Participation of master's aged athletes in triathlons has grown considerably in the last 10 years. Approximately 63% of triathletes are aged ≥35 years, and 43% are aged at least 40 years, so it is not surprising the most common age groups in triathlon are the 35-39 and 40-44 year categories (Loudon, 2016; Wright, 2012). Additionally, the 50 year and older age categories are experiencing more rapid increases in participation than the younger categories (Loudon, 2016). This occurrence is likely due to seasoned runners switching over to triathlon for the cross-training effect. Substituting some of the run sessions for swim or bike sessions allows for less impact on the musculoskeletal system and connective tissue than running alone. Overall, not only are the increases in participation of the master's age group beneficial for triathlon as a sport, but these older athletes may also experience factors related to successful aging.

Peak performances in the master's age category have greatly improved in endurance sports over the previous decades. With the increase of older adults participating in competitive events, such as triathlons, human performance records continue to be broken. For example, a 95-year-old male from Japan ran the 200-meter dash in 21.69. Likewise, a different 73-year-old person from Canada was the oldest individual to break 3-hours in the marathon (Tanaka, Seals,

& Tanaka, 2008). Ultimately, master's athletes are a rapidly growing subset of athletes that have unique training aspects, and carryover to lifespan health has potential.

Training Differences

The approach to training for master's aged athletes is much different than their younger counterparts. Outdated recommendations by sports medicine practitioners suggest that master's aged athletes, for example, should overall stop any rigorous training to prevent injuries because injury risk from training generally increases with age (Wright, 2012). The human body has a robust regeneration capacity that tends to further improve with physical activity participation. Therefore, athletes have a unique ability to recover from stressors. During aging, the ability to regenerate at the cellular level decreases training adaptation and recovery, leaving soft tissues stiff and susceptible to injury (Wright, 2012). Master's endurance athletes are also at greater risk for bone related injuries, particularly compared to older power athletes because the decrease in bone stimulating exercise related to endurance sports is less than power sports (Ireland et al., 2020). Therefore, more attention has been given to programming and performance measurements in the rapidly growing master's endurance athlete.

It is crucial to understand the physiological changes that occur during aging, and how these changes may correspond with training and recovery to enhance athletic performance. Running economy involves a balance between energy expenditure and skeletal muscle mechanics. Such running economy could be preserved if skeletal muscle maintenance and training intensity continues with age, however, research in this area is overall lacking (Tanaka et al., 2008). Muscle fiber composition could be important for maintaining running economy during aging. Another contributor to performance, lactate threshold, can also be preserved if training intensity is periodized correctly. Maximal aerobic consumption decreases roughly 10%

per decade beginning around ages 25-30 years if not adequately maintained (Tanaka et al., 2008; Wright & Perricelli, 2008). This decrease in aerobic consumption is likely associated with age-related reductions in maximal heart rate and stroke volume, which subsequently affects the arterio-venous O_2 difference and cardiac output (Tanaka et al., 2008). Additionally, limited time and declining motivation to train may factor into reduced training intensity, thereby leading to decreases in performance (Sinisgalli et al., 2021; Tanaka et al., 2008; Wright, 2012). Therefore, it is especially important for the master's athlete to train specifically for their changing physiology to continue improving on performance, prevent injury, and combat age-related body system changes.

To achieve optimal training adaptation for master's athletes, variants in training stimuli need to be addressed. Maintenance of maximal aerobic consumption (VO_2 max) and motor unit activation, requires the master's athlete to focus training heavily on VO_2 and anerobic sprint intensities to maintain the activation of type-II muscle fibers, neural innervation capabilities, and anaerobic power. It should also be noted that recovery and volume between and within intervals at VO_2 max should be emphasized due to the slowed recovery processes with aging (Broxterman, Layec, Hureau, Amann, & Richardson, 2017).

Performance Metrics

Training for the sport of triathlon and cycling is driven by analytics. Collected data can be used, for example, to predict performance metrics such as perceived exertion, power, and strength. In the year 2016, performance metrics of professional cyclists started to be released for facilitating fan engagement and sport promotion worldwide (Faiss, Sandbakk, Maier, Menaspà, & Abbiss, 2017). Observing data produced by professional athletes in maximum sprints to the finish, or the watts per kilogram produced on some of the most technical and challenging climbs in the world, created a sense of relatedness between professional athletes and sport fanatics.

The power meter is the most utilized performance device in triathlon and cycling for both amateurs and professionals. There has been a rapid expansion in the use of power meters, as different brands have released their own versions. Power meter locations on the bicycle can be found in the rear hub, pedal, crank arms, or bottom bracket on a bicycle (Faiss et al., 2017). Usage of a power meter allows a cyclist to see their power output measured in watts at any moment of a ride. The meter determines wattage by calculating the force created on the bicycle by the cyclist and the rate of the cyclist cadence. These data are then sent via Bluetooth to a watch or bicycle computer that displays data real time (Hurst, Atkins, Sinclair, & Metcalfe, 2015). Due to the nature of a power meter being mechanically driven, data from power meters in relation to training affects are highly accurate, and unaffected by environmental or physiological factors.

Training intensity zones for cyclists and triathletes can be calculated by the athlete themselves either at home, on an indoor trainer, or out on a flat road or sustained climb. The functional threshold power (FTP) test is a valid and reliable training measurement used by cyclists and triathletes to determine training intensity zones via a power meter (Fernando Klitzke Borszcz, Ferreira Tramontin, & Pereira Costa, 2020; Gavin et al., 2012; Klitzke Borszcz, Tramontin, & Costa, 2020; Sørensen, Aune, Rangul, & Dalen, 2019). The FTP measure is characterized as the highest average amount of power a single athlete can maintain in a pseudo-steady state for an hour. When an athlete exceeds their FTP, they will begin to utilize anaerobic substrates and fatigue will initiate. However, if an athlete works below their FTP, they will be working at a lower aerobic intensity and be able to maintain training intensity for longer (F. K. Borszcz, Tramontin, & Costa, 2019).

The three common methods of assessing FTP in cycling include the 20-minute average, 2x8-minute average, and the RAMP test. The 20-minute average involves an athlete undergoing a maximal exertion 20-minute bicycle leg, the average power output for the 20-minutes is then multiplied by 0.95 to determine FTP. A 2x8-minute test involves an athlete performing two all-out, eight-minute intervals separated by a five-minute rest interval. The two eight-minute intervals are then averaged and multiplied by 0.90 to determine FTP. Lastly, a RAMP test involves an incremental test with power increasing by 17-21 watts every minute until voluntary fatigue. The final one-minute average power ascertained is multiplied by 0.75 to similarly determine FTP. Assessing FTP is important because it allows athletes to establish their power training zones and specify the energy systems for training.

Another method of establishing training intensity zones is through heart rate and rating of perceived exertion (RPE). Heart rate training zones are created from objectively determining maximal heart rate or by using formulas to estimate maximal heart rate (e.g., age-predicted heart rate maximum) for defining training intensity (Sanders & Myers, 2017). Alternatively, RPE is a method that utilizes no equipment, only an athlete's perception of exertion. Many RPE scales including the simple 1-10 and traditional 6-20 Borg scales are frequently utilized (Sanders & Myers, 2017). Heart rate and RPE methods could be more cost effective relative to other measures of human performance that require expensive equipment, but unlike other assessments, factors such as physiological and environmental conditions can alter heart rate and exertion perception, thereby affecting training zone accuracy.

Another necessary training factor in triathlon and cycling that has a dramatic effect on performance is rate of force development (RFD). The RFD is the natural ability to produce the greatest amount of force in the shortest period of time. In cycling, this force is created in the form of torque, as force is being directed into the pedal that rotates the axis on the moment arm (Maffiuletti, Aagaard, Anthony, et al., 2016). The RFD is studied in many populations including athletes and older adults because of the importance to accelerate body mass in many situations such as sports and basic self-care (Callan et al., 2004). Cycling and triathlon utilize a greater combination of type-II muscle fibers than other endurance events like running. Therefore, more neural recruitment of large motor units containing type-II muscle fibers are created, leading to a greater RFD and potentially increased physical performance (Callan et al., 2004).

The Wingate Anaerobic Test (WAnT) is a well-validated 30-second maximal bicycle test that utilizes the ATP-PCr and anaerobic glycolytic systems for energy (Upan, Rata, Awson, Ile, & Ayn, 2009). WAnT measures peak power output (PPO), 30-second average power (anaerobic capacity), and fatigue index. PPO is correlated with RFD because it is typically produced within the first five seconds of the WAnT test. With age, there is a rapid decline in muscle strength, specifically power and rapid force production, and proper training can attenuate these changes in older athletes.

Resilience in sport is a psychological attribute that nurtures a positive adaptation when adversity is present (Extremera, Moreno, González, Ortega, & Ruz, 2016). Sport and athletic performance require substantial psychological motivation and task orientation. Cyclists and triathletes have a focus on psychological skills and mastery that aim to emphasize attention, motivation, and arousal, while managing emotions to decrease anxiety, pain, and fear that is associated with training and competition. Adaptation to internal and external stressors involves balancing body, mind, and spirit. This adaptation is sought after to increase an individual's resilience (Connor & Davidson, 2003; Sarkar & Fletcher, 2014). High levels of physical exertion disrupt normal routine, which challenge psychological skills. Therefore, like physical training, mental training is equally important for performance.

Several scales such as the Connor Davidson Resilience Scale (CD-RISC) have been developed to measure resiliency (Connor & Davidson, 2003). The CD-RISC is a 25-item model comprised of five specific psychology factors including personal competence, trust in instincts, strengthening of the effects of stress, locus of control, and spiritual awareness. This 25-item model focuses on measuring positive adaptations from facing adversity. The CD-RISC has been shown to be valid and reliable in many populations including athletes (Olmo Extremera et al., 2016).

Potential Problems with Current Measures

The power meter was developed over four decades ago by a single company, Schoberer Rad Messtechnik. Today there are dozens of companies with many price points that have created their own version of the power meter (Passfield, Hopker, Jobson, Friel, & Zabala, 2016). A bicycle is propelled by creating torque to a pedal about an axis point that drives the movement of a chain and gears to rotate the wheels. Due to the propulsive transmission of the bicycle, power meters can be located on many bicycle locations (Klika, Alderdice, Alderdice, Kvale, & Kearney, 2007; Passfield et al., 2016; Sitko, Cirer-Sastre, Corbi, & López-Laval, 2020). These power meters are essentially strain gauges that measure torque created by the force applied to the bicycle pedal and the revolutions about the axis from the cyclist (Passfield et al., 2016). Each power meter location utilizes a different formula to measure power, therefore, there is inconsistent reliability between different power meter types. Additional reliability issues exist when the power meter is used in different environments because temperature and humidity affect accuracy. Moreover, some power meters require calibration or regular firmware updates, which further decreases reliability and utility between location and brand (Gavin et al., 2012; Hurst et al., 2015; Passfield et al., 2016).

Conclusion

As the sport of triathlon and cycling becomes more popular at the master's age categories, research on master's athletes will continue growing. The ability to understand specific training intensities based on aerobic and anaerobic performance, and to remain calm and resilient when faced with adversity during life, training, and racing, may lead to sport accomplishments. Current measures of FTP, VO_2 max, anaerobic capacity, and peak power are quite invasive and require significant recovery time. Therefore, the emergence of a new measure that requires minimal time and effort with low physiological and physical stress may benefit the master's aged athlete.

CHAPTER 2: LITERATURE REVIEW

The Master's Athlete

By the year 2060, the older American population is projected to increase by about 112% (Lutz, Sanderson, Andruchowitz, & Scherbov, 2008). This projected surge in older Americans will also present increases in age-related health conditions. The body system changes that occur during aging lead to decreased maximal aerobic power, anaerobic capacity, muscle strength, and peak muscle power output. These age-related declines in physical functioning will similarly influence human performance for master's athletes. Therefore, maintaining training across the lifespan, and even beginning to participate in physical activities included in triathlete training at a novice level, may help to preserve physical functioning during aging.

To be a competitive master's triathlete or cyclist, athletes engage in strict training to combat age-related body system changes. The master's athlete has been considered a model of successful aging because of their sustained healthy lifestyles (Wooten et al., 2021). An example of a successful master's athlete, Dave Scott, a six-time world champion in the Ironman distance triathlon who returned from retirement at the age of 40 years to place second in the Ironman world championships in Kona, just missed his seventh overall world championship title (Wright, 2012). Peak endurance performance plateaus around 35 years of age and slowly decreases into the mid 50's, wherein larger changes are experienced (Tanaka et al., 2008; Wright & Perricelli, 2008). For instance, after the age of 50 years, there is a 12-13% decrease in full Ironman triathlon performance each decade for males, and a 14-15% decrease in performance each decade for females (Lepers, 2020). As popularity of triathlons at this age level continues climbing, overall athlete performance will also continue to propel, therefore, understanding performance metrics and physical changes in master's athletes are important.

Physiological Changes

Competitive master's athletes strive to maintain human performance by confronting the inevitable declines in physiological functioning during aging. Endurance performance is typically based on three major factors: VO_2 max, lactate threshold, and exercise economy. Decreases in VO_2 max are associated with changes in several other measures. VO_2 max is generally dependent on maximal heart rate, cardiac output and stroke volume, and the a-VO_2 difference (Tanaka et al., 2008; Wright, 2012; Wright & Perricelli, 2008). In sedentary individuals alone, there is about a 10% decline in VO_2 max beginning at the age of 30 years, which can be slowed if these persons begin participation in endurance training and remain persistent. However, a roughly 7-10 beats per minute reduction in heart rate each decade contributes to decreased VO_2 max. Additionally, cardiac output declines from reductions in overall stroke volume with age (Willy & Paquette, 2019; Wright, 2012).

VO_2 max

Eskurza et al, (2002) sought to evaluate age-related declines of VO_2 max in sedentary (n=8; age: 57.0 ± 1.7 years) and endurance trained women (n=16; age: 51.0 ± 2.3 years), while also seeking to examine if the decrease in VO_2 max for the endurance trained women was related to decreased overall training volume and intensity. Endurance trained women recorded their current training regimen specifically to intensity, duration, volume, and workout type for the previous two weeks. Both groups performed incremental VO_2 max protocols on treadmills wherein the endurance trained group ran and the sedentary group walked. This longitudinal study applied the same protocols again seven-years later and found decreases in VO_2 max for both sedentary (-0.40 ± 0.12 ml/kg/min) and endurance trained women (-0.84 ± 0.15 ml/kg/min; $p<0.001$). Decreases of VO_2 max were higher in the endurance trained women who showed a reduction in overall training volume (-1.04 ± 0.16 ml/kg/min; $p<0.05$). It is also important to note that the largest changes associated with VO_2 max were due to the moderate correlation in reduction of training volume ($r=0.63$; $p<0.05$) and not intensity or frequency of training (Eskurza et al., 2002).

A separate study used a single group pre-post design to measure VO_2 max and isometric knee extension torque 24 hours prior to an Olympic distance triathlon, and again 24 hours after the race. This study found a strong correlation in reduction of VO_2 max and relative ventilation thresholds following an Olympic distance triathlon in master's triathletes compared to young triathletes ($r=0.76$; $p<0.05$) with an observed rate of decline in master's athletes of (-4.1% ml/kg/min; $p<0.05$) (Sultana, Abbiss, Hausswirth, & Brisswalter, 2012). These findings suggest the importance of maintaining endurance training volume to maintain VO_2 max.

Other methods have likewise been used to predict age-related declines in athletic performance in master's athletes. Capelli, Riiveger, Bruseghini, Calabria, and Tim (2016) utilized an algorithmic procedure to minimize the differences between metabolic power for covering the race distance and the maximal metabolic power needed to maintain the effort in a 3000m track event in separate cycling age categories (30-35 to 75-79 years). This study found that, starting at the age of 45 years, there was a 16% decrease in VO_2 max for each oncoming decade of life ($p<0.05$). Additionally, anaerobic capacity decreases at a rate of 11% starting at the age of 45 years and continues decreasing at the same rate every 10 years ($p<0.05$) (Capelli, Rittveger, Bruseghini, Calabria, & Tam, 2016). This decrease in VO_2 max suggests that even with a maintenance of training volume and intensity, the physiological changes associated with aging, such as increased loss of oxygen delivery to the skeletal muscle or decreases in oxygen diffusion at the capillaries, are unavoidable.

Exercise Economy

Exercise economy is determined by measuring oxygen consumption at a specific sub-maximal intensity below the anaerobic threshold (Tanaka et al., 2008; Wright, 2012). Exercise economy can be measured by total energy expenditure at a specific workload (Peiffer, Abbiss, Sultana, Bernard, & Jeanick, 2016). A systematic review suggested that age related declines to physiological functioning may not affect exercise economy (Tanaka et al., 2008). However, this suggestion could be confounded by some studies that assessed master's athletes earlier in life such as at ages 35-45 years before larger declines in exercise economy could be observed (Borges, Reaburn, Doering, Argus, & Driller, 2018; Fell & Harrison, 2008; Peiffer et al., 2016; Tanaka et al., 2008; Wright & Perricelli, 2008).

Peiffer et al, (2016) sought to determine differences in exercise economy between young (n=20; age: 28.5 ± 2.6 years) and master's aged triathletes (n=20; age: 59.8 ±1.3 years). Participants in this study performed four different tests separated by 48-hours. Each participant completed a graded exercise (GXT) VO_2 max test to volitional fatigue for cycling and running. Cycling efficiency was determined by riding at 65% of maximal aerobic power for 10-minutes and expressed by measuring the total kilojoules and energy expenditure during the 10-minute period. Running efficiency was classified by performing a 10-minute run at 65% speed of VO_2 max and energy expenditure was recorded as the ratio of oxygen consumption to speed. The findings suggested that master's triathletes cycling efficiency was 14.7% lower relative to lean body mass than young triathletes (336.6 ml/kgLB/min ± 11.6 ml/kgLB/min; $p<0.05$). Additionally, the energy cost of running in master's triathletes was 22.1% higher compared to young triathletes (247.1 ml/kg/min ±10.1 ml/kg/min; $p<0.05$) (Peiffer et al., 2016). In contrast, Sultana et al, (2012) found running efficiency 24-hours following an Olympic distance triathlon to lack differences between master's (n=10; age: 52.4 ± 10years; -0.8 ± -2.9%) and young athletes (n=9; age: 28.4 ± 6.1 years; 2.6 ± -1.8%; $p>0.05$). These findings show that steep declines in exercise economy for master's triathletes may occur starting at about age 55 years.

Lactate Threshold

Lactate threshold is quantified as the point at which lactate concentration in the blood increases beyond the body's buffering capacity when exercise intensity elevates (Forsyth, Burt, Ridley, & Mann, 2017). Lactate threshold is an important factor in endurance performance because lactate threshold can be used to determine training adaptations and quantify endurance capacity. Interestingly, lactate threshold may not be a good predictor of performance in master's athletes due to a decrease in lactate production from decreased enzyme activity and VO_2 max (Coggan et al., 1990; Forsyth et al., 2017). Therefore, if net lactate concentrations are low, lactate threshold may not be an appropriate measure for examining training adaptations and endurance because blood lactate levels in master's athletes may not accumulate until intensity is too high.

With low net lactate concentrations, other methods to determine lactate threshold have been studied in master's runners. Forsyth et al, (2017) utilized the lactate maximal deviation method, which determined the maximal distance between the line of best fit when graphing lactate concentrations in master's runners (n=36; age: 45.5 ± 7.0 years). This investigation revealed a strong, positive correlation in the maximal deviation method for predicting 5-km treadmill performance in master's runners ($r=0.92$; $p<0.001$) (Forsyth et al., 2017). Likewise, Fell (2008) utilized a cross-sectional design to test the lactate maximal deviation method to determine 30-mile time-trial performance in trained master's cyclists (n=9; age: 45.0 ± 6.0 years). Master's cyclists completed an incremental cycling test to determine peak power output and heart rate maximum at lactate threshold. Participants then completed a 30k time trial at predicted paces. This study showed similar findings to Forsyth et al, (2017), such that a strong, positive correlation between the maximal deviation methods and 30-mile time-trial performance in master's cyclists existed ($r=0.90$; $p<0.001$) (Fell, 2008).

Recovery

Recovery is a specific training aspect that is important for master's athletes. Due to elevated age, master's athletes require greater recovery time from acute exercise training sessions than younger athletes (Loudon, 2016). However, research in this area is generally mixed on the recovery response from training between master's and younger athletes, with some studies suggesting there is a difference in skeletal muscle damage and peripheral recovery (Borges et al., 2018; Lepers, 2020). Therefore, it could be suggested that with the increase in master's participation and training knowledge, lack of recovery may be due to a decrease in overall training volume and intensity rather than aging.

A recent, repeated measures study was conducted to examine the difference in recovery between well-trained master's (n=9; age: 55.6 ± 5.0 years) and young cyclists (n=8; age: 25.9 ± 3.0 years) from high intensity interval training (HIIT) (Borges et al., 2018). All participants underwent a preliminary three second knee extensor isometric maximal voluntary contraction (MVC) and GXT. Approximately 72-hours later, participants completed a maximal 10-second sprint and 30-minute time trial on a bicycle ergometer. Following another 72-hours of recovery, athletes engaged in HIIT. To measure recovery, perceptual measures of current fatigue, motivation, total quality of muscle recovery, and muscle soreness were recorded. This study found no significant differences between pre- and post-test performance measures (MVC and GXT) and hematological creatine kinase measures between master's and young cyclists (ES 0.11

± 0.55, $p > 0.05$). Only a moderate difference was recognized in master's athletes, as they reported lower levels of motivation at the 48-hour recovery time period (ES = 0.69 ± 0.77; $p < 0.05$) (Borges et al., 2018).

Similar to Borges et al, (2018), Fell and Harrison (2008) evaluated differences in recovery for young (n=9; age: 24.0 ± 5.0 years) and master's (n=9; age: 45.0 ± 6.0 years) aged trained cyclists. Participants similarly completed a baseline GXT test. This study utilized a repeated measures design to have participants return at the same time on a different day to state criterion measures rating of physical fatigue, total quality of recovery, and motivation. Additionally, participants completed a knee extension and 30-minute time trial test. Unique to the current study, participants performed three, 30-minute time trial tests back-to-back for three consecutive days. Criterion measures of fatigue, soreness, motivation, and recovery were measured after each time trial. This study found that the master's trained cyclists reported greater overall soreness (master's effect size (ES): 2.28, young 0.54; $p < 0.05$), fatigue (master's ES: 0.87, young 0.44; $p < 0.05$), and recovery (master's ES: 0.86, young 0.43; $p < 0.05$) without any changes in 30-minute time trial performance compared to the younger trained group ($p > 0.05$). Additionally, motivation between the two groups, as measured by perceptual feelings of motivation, was not different (master's ES: 0.6, young 0.17; $p > 0.05$), thereby countering the findings of other research on this topic (Borges et al, 2018).

Skeletal Muscle Changes

Skeletal muscle mass begins to decline at about 35 years of age, which subsequently leads to losses in many performance-related measures. Type-II muscle fibers also decrease in size or quantity beginning around 35 years of age and continue to decrease at a rate of 1.1%-1.5% each year following (Hawkins et al., 2003; Lexell, 1992). In endurance athletes, maintenance of type-II muscle fibers is important for RFD and power production at various points during a race (Capelli et al., 2016). The importance of strength training in master's athletes to maintain type-II muscle fiber size and activation has been emphasized because endurance training alone may not preserve type-II muscle fiber size (Harridge, Magnusson, & Saltin, 1997; Hawkins et al., 2003). For instance, in a cross-sectional investigation of master's aged runners (n=15; age: 72.8 ± 5.4 years), force production had a weak, negative correlation with age (r=-0.061; p<0.01) (Harridge et al., 1997). Additionally, Korhonen et al, (2006) discovered type-II muscle fiber size in master's sprinters through muscle biopsy (n=91; age: 75.3 ± 0.9 years) to be significantly lower than young-trained sprinters (n=53; fibers; age: 24.3 ± 1.0 years) (3,080 ± 190 μm^2 vs. 4,930 ± 140 μm^2, n=47 fiber; p<0.001). These findings suggest strength training and high intensity exercise should be applied in master's cyclists and triathletes training to help maintain size and activation of type-II muscle fibers.

Performance Metrics

Performance metrics have routinely been analyzed in young, trained athletes. Unfortunately, the physiological changes related to aging in master's athletes may be different than the currently available normative data (Peiffer, Abbiss, Chapman, Laursen, & Parker, 2008). A proper understanding of performance metrics for exercise scientists and coaches would assist with categorizing performance indicators in master's athletes. Therefore, it is important to examine how various performance metrics are measured in master's triathletes and cyclists.

Power meters can be equipped to each individual bike and have effectively become an essential tool in cycling and triathlon. During endurance testing, exercise intensity is best determined through monitoring power output. Power is considered the gold standard in examining exercise intensity because it measures intensity mechanically and is not affected by physiological or environmental variables (Allen, Coggan, & McGregor, 2019; Passfield et al., 2016). Alternatively, heart rate and RPE can be affected by physiological, environmental, subjective, and nutritional factors (Boullosa et al., 2020). Therefore, to effectively monitor training intensity zones and specific areas of improvement, determining FTP via testing is preferred.

Functional Threshold Power Testing

As stated previously herein, FTP is a valid and reliable method for quantifying training intensities. FTP is the average amount of power an individual can maintain for a 60-minute time period (Borszcz et al., 2018). FTP is presented as watts. A high overall FTP is coveted for cycling and triathlon performance (Sitko et al., 2020). Determining anaerobic threshold in a lab setting requires multiple days, blood measures, and a high cost. Thus, FTP is mostly recommended in amateur and elite athletes (Mackey & Horner, 2021).

FTP testing helps athletes determine specific training intensities for monitoring and distributing efforts. The term "threshold" has been used loosely and interchangeably for FTP. Threshold is often deemed as, for example, anaerobic threshold, lactate threshold, onset of blood lactate accumulation, or maximum lactate steady state (Allen et al., 2019; Borszcz et al., 2019; Fell, 2008; E. McGrath et al., 2019). FTP is a functional and mechanical measure for triathletes and cyclists to determine their set point of anaerobic threshold and buffering capacity. The FTP test is considered the maximal power output an individual can maintain for a 60-minute time period (E. McGrath et al., 2019). Establishing FTP is useful for triathletes and cyclists because it can be ascertained in their own home or on local roads. Several methods have been deployed to determine FTP in a shorter time frame including the 20-minute test, 2x8-minute test, and the RAMP test.

Surrogate to Anaerobic Threshold

Many investigations have shown that the at-home FTP field test is adequate for lab-based blood lactate testing (Gavin et al., 2012; E. McGrath et al., 2019; Valenzuela & Lucia, 2018). A cross-sectional study of highly trained cyclists (n=19) comparing the 20-min FTP test to blood lactate measures revealed the 20-minute FTP test has no statistical difference between blood lactate measures of 5mmol or greater (6.9 ± 1.3 mmol vs. 6.9 ± 1.9 mmol; $p \geq 0.05$). These findings suggest the at-home FTP test is a reliable and valid measure to a lab-based lactate threshold test. Additionally, the 20-min prediction test was statistically similar in comparison to the full 60-minute test (0.19 ± 0.02 W·kg; $p < 0.05$) (E. McGrath et al., 2019).

Another cross-sectional study compared the 20-minute FTP test to a cyclist's anaerobic threshold. Trained (n=9; age: 33.0 ± 8.0 years) and recreational cyclists (n=11; age: 32.0 ± 5.0 years) performed a graded VO_2 max test and 20-minute FTP test with lactate measurements collected during testing. This study found no differences between the 20-minute FTP test and lactate threshold test in all cyclists (ES=0.20; $p = 0.08$). When analyzing participants separately between trained and recreational status, very strong positive correlations were observed for the 20-minute FTP test and lactate threshold in the trained cyclist's group ($r = 0.95$; $p < 0.001$), and recreational cyclist's group ($r = 0.88$; $p < 0.01$) (Valenzuela & Lucia, 2018). In alignment with these findings, Borszcz, Tramontin, and Periera Costa (2019) sought to determine the relationship between the 20-minute FTP test to anaerobic threshold and found a strong, positive correlation ($r = 0.80$; $p < 0.05$) between these measures in 15 trained male cyclists. These findings suggest that lactate threshold can be determined with FTP testing and are probably linked to trained cyclists.

At-Home Testing

Master's athletes can utilize the FTP test in the presence and safety of their own home. The at-home cycling experience has evolved greatly over the years, and in part due to the COVID-19 pandemic, at-home training has become one of the top 20 worldwide fitness trends (McIlroy, Passfield, Holmberg, & Sperlich, 2021). At-home stationary bicycles, such as Peloton or Nordic Track, have become popular for attending spin classes. However, in triathlon and cycling, the ability to ride a bicycle inside while being protected from weather and traffic is attractive. With the emergence of virtual online platforms for bicycle training, direct drive trainers are now equipped with smart technology to provide a real life experience (McIlroy et al., 2021; Rojas-Valverde, Córdoba-Blanco, & González-Salazar, 2021).

Virtual reality training platforms are highly dependent on mechanical variables of the cyclists, such as, weight, power and pedaling efficiency. Power update rate could be substantial in various virtual platforms, and therefore, power update rate is a viable method of at-home training. In a case-by-case analysis on recreational cyclists (n=21; height: 175.9 ± 7.5 cm; weight: 76.5 ± 13.9 kg) power update rate was analyzed in seven different virtual conditions and compared to heart rate, mechanical efficiency, and cycling distance. The findings from this work indicated that power update rate should be utilized in virtual reality training platform designs ($p<0.01$) (Lazzari, Diefenthaeler, & Marques, 2019). These platforms uniquely allow amateur and elite cyclists and triathletes to ride, race, and train in virtual worlds against and amongst each other.

Peak Power Output

Peak power output (PPO) is a frequently used performance test in triathletes and cyclists to determine performance status or changes for predicting cycling talent (Lamberts & Woolrich, 2009). A cross-sectional investigation analyzed the typical error of measurement in PPO tests in well-trained cyclists (n=17; age: 31.0 ± 4.0 years). On average, error of measurement in well-documented cycling performance tests was 2-3%. This study suggests that no statistical differences between three PPO tests and a small error of measurement (M=3.5w; 0.9% change; $p>0.05$) (Lamberts & Woolrich, 2009). Alternatively, in another cross-sectional study, the age-related effects of PPO on master's cyclists (n=32) in three different age categories were evaluated, 35-44 years (n=14; age: 39.0 ± 3.0 years), 45-54 years (n=10; age: 49.0 ± 3.0 years), and ≥55 years (n=8; age: 65.0 ± 4.0 years). This study found that differences in PPO between the 45-54 years age group (392.0 ± 36.0 watts $p<0.05$) and ≥55 years age group (324.0 ± 54.0 W; $p<0.05$) (Peiffer et al., 2008). These findings suggest PPO declines with advancing age.

PPO has also been shown to be highly correlated with cross-country mountain bike performance. Male regional, international, and national mountain bikers (n=13; age: 20.0 ± 1.0 years) participated in a cross-sectional study, and the results from this investigation revealed strong, negative correlations between PPO and mountain bike performance in highly trained cyclists ($r=-0.71$; $p<0.01$) (Impellizzeri, Rampinini, Sassi, Mognoni, & Marcora, 2005). Additionally, in a two-part study, PPO was analyzed to predict VO_2 max and 20-km time-trial performance in trained triathletes and cyclists (male, n=54; age 29.4 ± 6.6 years; female, n=46; age 32.2 ± 6.8 years). PPO was shown to be strongly and negatively correlated with VO_2 max ($r=-0.97$; $p< 0.001$). Of the 19 participants who completed part two of the study, strong and negative correlations between PPO and 20-km time-trial performance were observed ($r=-0.91$; $p<0.001$) (Hawley & Noakes, 1992). As such, PPO could be a strong indicator of performance in triathletes and cyclists.

Motivation

Training and competition in triathlon and cycling requires a vast amount of dedication and motivation to achieve a goal. Given the unique barriers that master's athletes face during training, it is recommended that master's athletes find an inner purpose in training and competing. An achievement goal is generally defined as the purpose of task engagement (Elliot & Church, 1997). The fear of failure is a prohibitor of performance when achievement motivation is not utilized (Elliot & Church, 1997). Additionally, it is recommended that triathletes and cyclists have low levels of nerve instability so they can react to physically challenging situations in a race, while having high levels of achievement motivation to remain task oriented (Kovářová, Pánek, & Bunc, 2014). Therefore, achievement motivation, performance approach goals, along with development of mastery are likely components of master's athletes as they pursue endurance performance through achievement motivation patterns.

Achievement Motivation

Achievement motivation is associated with thought patterns, feelings, and actions in sport, and have also been used to explain short-term positive outcomes (Hodge, Allen, & Smellie, 2008). Moreover, Halvari and Kjormo (1990) stated the motive to achieve success is an inclination to positive outcomes in situations individuals perceive as challenging. Master's athletes could be characterized as task-oriented individuals who are motivated through challenges in training and competing. In a motivation questionnaire study on master's athletes (n=373) at the New Zealand master's games compromised of six sports (swimming, n=41; golf, n=81; tennis, n=39; soccer, n=90; field hockey, n=50; netball, n=72; age: 48.0 ± 9.6 years), achievement motivation and motivational correlates in master's sport on a 1 (not at all) to 5 (a lot) Likert scale were examined. Achievement goal findings included high levels of task orientation (M=3.89 ± 0.41) and relatively low levels of ego orientation (M=3.05 ± 0.49) (Hodge et al., 2008). Similar to achievement motivation, performance approach goals are terms that have often been used interchangeably in literature.

Performance Approach Goals

Performance approach goals are associated with an outcome focus and often used in alignment with extrinsically motivated goals (Hulleman, Schrager, Bodmann, & Harackiewicz, 2010). These goals indicate performance focus is related to task orientation and affirmation of self-worth to an audience. Similarly, performance approach goals are attached to the motive to succeed and avoid failure (Halbari & Kjormo, 1999). A qualitative investigation sought to determine why senior-class students (n=53) from two urban schools pursued performance related goals on classroom performance via one-on-one interview. The investigators noted performance related goals are highly linked to extrinsic motivation, such as appearance-approach goals and competition-approach goals. After completing 15 to 30-minute interviews, response rates were spread evenly as appearance-approach (97 statements, 31%) and competition–approach (106 statements, 36%). Twenty-one participants (38% of the sample) made appearance–avoidance statements, whereas 22 students (40%) made competition–approach statements (Urdan & Mestas, 2006). These findings indicate that senior-class high school students are mixed on their reasons for classroom performance, even if responses were highest in competition-approach.

In contrast, performance approach goals could be greatest in those who plan to achieve success in future sport related goals, which leads to early preparations and a larger devotion of time to avoid failure (Halbari & Kjormo, 1999). In another qualitative study, athletic performance in elite athletes (n=136) from the Olympic Top Athlete Project was examined. Of the six measured variables high mean scores were associated with "The motive to achieve success" (M=26.6 ± 3.5) and not equal to "Performance approach goal" (M=40.9 ± 6.3) (Halbari & Kjormo, 1999). These findings align with motives of master's triathletes and cyclists.

Handgrip Strength

Traditional spring-type and hydraulic handgrip dynamometers conveniently assess strength capacity in a variety of settings (Klawitter et al., 2020). Handgrip strength (HGS) is a viable measure for determining overall muscle function with handgrip dynamometers (Klawitter et al., 2020; Mahoney et al., 2020). Muscle strength is an important aspect of muscle function, and poor muscle function is a hallmark risk factor for unsuccessful aging. Low HGS is associated with several adverse health outcomes (Mahoney et al., 2020). While measures of HGS have been routinely collected in general older adult populations, limited studies have been conducted for HGS as a measure of human performance in older (master's) athletes.

Coaches and master's athletes could be interested in using HGS as simple and non-invasive measure of human performance. For example, a cross-sectional study of male college basketball players (n=14; age: 20.4 ± 1.6 years) sought to determine if low HGS was associated with higher injury risk and basketball performance. Interestingly, the study found that lower, left HGS was moderately and negatively correlated with minutes played ($r=-0.57$; $p<0.05$), rebounds ($r=-0.55$; $p<0.05$), and steals ($r=-0.67$; $p<0.05$), but right HGS showed no benefits in basketball performance. Low HGS was also a non-predictor for injury in basketball players ($p\geq0.05$) (McGill, Anderson, & Horne, 2012).

Another cross-sectional study included 78-national level Portuguese swimmers of three different age categories: juvenile (n=11 males; age: 15.0 ± 0.5 years, n=10 females; age: 12.5 ± 0.5 years), junior (n=10 males; age: 16.4 ± 0.5 years, n=14 females; age: 14.6 ± 0.5 years), and senior (n=18 males; age: 21.3 ± 2.3 years, n=15 females; age: 18.6 ± 2.3 years). HGS and swim performance in four different swim strokes (freestyle, breaststroke, back stroke, and butterfly) were examined. The findings from this study revealed moderate and positive correlations in dominant ($r=0.54$; $p<0.01$) and non-dominant ($r=0.53$; $p<0.01$) HGS for the 100m freestyle, and moderate and positive correlations in the dominant ($r=0.59$; $p<0.01$) and non-dominant ($r=0.51$, $p<0.05$) hands in the 200m freestyle in senior level female swimmers. Only male junior swimmers experienced moderate and positive correlations for the dominant hand ($r=0.63$; $p<0.05$), and strong and positive correlations for the non-dominant hand ($r=0.71$; $p<0.05$) in the 100m freestyle (Garrido et al., 2012). It should be noted that the freestyle swim is the primary swim technique for triathlon.

HGS has also been shown to be linked to freestyle swim performance in master's elite swimmers. Another cross-sectional investigation sought to determine if HGS was associated with freestyle swim performance in different elite master's swimmer's events: 50m (n=30; age: 56.43 ± 11.57 years), 100m (n = 32; age: 55.41 ± 9.80 years), 200m (n = 23; age: 58.09 ± 9.94 years), 400m (n = 26; age: 56.62 ± 12.79 years), and 800m (n = 24; age: 57.29 ± 8.19 years). This study showed HGS was differentially negatively correlated with swim performance in freestyle events in elite master's swimmers: 50m ($r=-0.72$; $p<0.01$), 100m ($r=-0.57$; $p<0.01$), 200m ($r=-0.58$; $p<0.01$), 400m ($r=-0.57$; $p<0.01$), and 800m ($r=-0.39$; $p<0.01$) (Zampagni et al., 2008). In contrast, HGS measures of endurance have also been compared to muscle of the knee extensors in male and female healthy participants (n=8 males, age: 24.1 ± 1.7 years; n=13 females, age: 23.1 ± 1.0 years). Participants underwent a maximal intermittent endurance test consisting of 12 isometric contractions for three seconds with five seconds of rest between repetitions. This procedure was utilized for both knee extensor endurance and HGS endurance.

However, this study showed no significant correlations between HGS endurance and knee extensor measures (r=-0.090; p=0.75).

Additional Handgrip Measurements

Although maximal HGS is effective in predicting many adverse health outcomes, maximal HGS alone may not generalize to muscle function as a whole. Maximal HGS is only one single aspect of muscle function. There are many physiological and mechanical body systems that could contribute to performance outcomes more effectively. Traditional and spring-type handgrip dynamometers are only useful in detecting strength capacity. Novel electronic handgrip dynamometers provide a unique quality in assessing additional HGS measurements that may further evaluate muscle function beyond maximal HGS (McGrath et al., 2021). Specifically, electronic handgrip dynamometers can assess RFD and fatiguability, which may relate to the same physiological mechanisms as PPO and FTP in cycling. Testing the diversity of muscle function through new HGS measurements via electronic handgrip dynamometry, could better operationalize muscle function and perhaps, help to quantify characteristics of human performance.

RFD is known as the time component when producing maximal force. This force-time curve is uniquely related to muscle function because it accounts for the neural component. The neuromuscular system is a sensory motor sequence, whereby we receive sensory information and the brain notifies our muscles about how much force is needed for a contraction (McGrath et al., 2021). Another method for predicting muscle function, fatiguability, is the fleeting decrease in the ability to perform muscle actions at various intensities. McGrath et al, (2021) proposed that HGS fatigability requires squeezing the electronic dynamometer in a maximal MVC until 50% maximal HGS cannot be maintained. Further, HGS asymmetry is another predictor of poor health. Population-based studies have collected maximal HGS from both hands, allowing for additional muscle function screening beyond maximal HGS alone (McGrath et al., 2021).

A pilot-level cross-sectional study of 13 adults aged 70.9 ±4.0 years sought to examine the relationships between maximal HGS, radial and ulnar digit grip strength, submaximal HGS force control, HGS fatigability, neuromuscular HGS steadiness, and HGS asymmetry as measured with an electronic handgrip dynamometer. A principal component analysis was conducted on the HGS variables and maximal strength (maximal HGS, radial digits strength, ulnar digits strength), contractile steadiness (maximal HGS steadiness, ulnar digits grip steadiness), and functional strength (submaximal HGS force control, HGS fatigability, HGS asymmetry, HGS fatigability steadiness) emerged as dimensions from the HGS measurements evaluated (significant factor loading (|>0.40|)). These findings suggest that the other aspects of muscle function, as measured by electronic handgrip dynamometry, may separate themselves from maximal HGS, thereby suggesting a potential HGS battery (Mahoney et al., 2020).

Functional asymmetries between limbs may represent another form of muscle impairment that may contribute to health problems during aging. A secondary analysis of publicly available National Health and Nutrition Examination Survey data (n=3483 adults aged 65.6 ± 10.3 years) sought to determine if HGS asymmetry (>10% HGS between hands) was associated with multi-morbidity, which included two or more of the following conditions: cardiovascular disease, chronic lung disease, chronic kidney disease, asthma, arthritis, cancer, stroke, high blood pressure, high cholesterol, and diabetes. Relative to persons without asymmetry, those with HGS asymmetry had 1.31 (95% confidence interval (CI): 1.03, 1.67) greater odds for multimorbidity. Further, persons with asymmetric HGS had 1.22 (CI: 1.04, 1.44) greater odds for accumulating morbidities (Klawitter et al., 2021).

A similar investigation examined the longitudinal associations between asymmetry, weakness, and morbidity accumulation with data from 18506 adults aged 65.0 ± 10.2 years who participated in the Health and Retirement Study. Participants with asymmetry again had >10% strength between hands, while men and women with weakness had maximal HGS <26-kilograms and <16-kilograms, respectively. Morbidities included hypertension, diabetes, cancer, chronic lung disease, cardiovascular disease, stroke, arthritis, and psychiatric problems. The analyses showed that each weakness and asymmetry group had greater odds for future accumulating morbidities: 1.27 (CI: 1.11, 1.45) for weakness alone, 1.09 (CI: 1.04, 1.14) for asymmetry alone, and 1.46 (CI: 1.29, 1.65) for both weakness and asymmetry. These findings suggest that when weakness and asymmetry are both present, risk for disease may increase during aging (Klawitter et al., 2020).

Likewise, a secondary analysis of data from the Osteoporotic Fractures in Men study was conducted to examine the associations between HGS asymmetry and leg extension power asymmetry on risk of incident recurrent falls and fractures in older men. A handgrip dynamometer was used to determine asymmetry and a Nottingham Power Rig ascertained leg extension power. Older men in the highest HGS asymmetry quartile had a 1.20 (CI: 1.01, 1.43) relative risk for incident recurrent falls. Moreover, men in the highest HGS asymmetry quartile had a higher risk for incident fractures: 1.41 (CI: 1.02, 1.96) for hip, 1.28 (CI: 1.04, 1.58) for major osteoporotic, and 1.24 (CI: 1.06, 1.45) for non-spine. However, there were no significant associations between leg extension power asymmetry and recurrent falls or fractures. These findings suggest that HGS asymmetry could be a risk factor for predicting mobility related outcomes. Moreover, HGS asymmetry is simpler to measure and may have a similar prognostic value to that of lower extremity power for falls and fractures (McGrath, Blackwell, Ensrud, Vincent, & Cawthon, 2021). Further advancing assessments of muscle function may improve the measurement of human performance in master's triathletes and cyclists. Maximal HGS, asymmetry, fatiguability, and RFD may provide feasible insights into human performance during aging.

Future Applications

Indeed, the number of master's aged triathletes and cyclists is high and will continue to grow. Identifying human performance assessment modes that are simple to complete and informative for master's athletes may have value for helping them maintain training-life balance and time to recovery. Current validated measures including lab based VO_2 max testing, lactate threshold assessments, and at home FTP examinations require a substantial amount of time and motivation. Additionally, the physiological, mechanical, and mental fatigue associated with lab-based lactate threshold testing and VO_2 max testing, or at home FTP testing are exhaustive and require rest to be scheduled in the training program, thereby delaying training adaptations. Likewise, various motives including achievement motivation and performance goal setting may be more effective for non-fatiguing tests that do not require vast mental preparation time.

The additional aspects of muscle function, as measured with electronic handgrip dynamometers, may have promise for evaluating human performance. Characteristics that are predictive of human performance, such as the RFD and fatigability, can be feasibly measured with electronic handgrip dynamometry instead of other more invasive measures. Psychosocial factors, such as resilience and achievement motivation, may also provide insights for how the additional handgrip measures are linked with human performance. Therefore, more research is warranted for examining how the additional handgrip measurements are associated with human performance in master's aged triathletes and cyclists (Klawitter et al., 2021).

CHAPTER 3: METHODOLOGY

The aging athlete experiences a multitude of physiological and mechanical changes related to human performance. Beginning at about the fourth decade of life, there is a reduction in skeletal muscle strength and force development, and decreases in VO_2 max, exercise economy, lactate threshold, and recovery from exercise induced stress (Wright, 2012; Wright & Perricelli, 2008). Additionally, athletes in the master's age category typically have to navigate a full-time job, family, and social life, thereby making it difficult to balance appropriate training loads.

Several motivational factors contribute to the dedication of a master's athlete training plan. Master's athletes are often driven by internal and external achievement outcomes, and performance evaluations that are non-fatiguing and anti-invasive may provide assessment utility. HGS is a simple and feasible measure for assessing total body strength. However, maximal strength is only a single aspect of muscle function. Several other attributes help to characterize muscle function and examining these aspects with sophisticated dynamometer technologies may predict human performance in master's athletes.

Purpose

The purposes of this study were to:

1. Determine the correlations of maximal HGS, rate of HGS rate of force development, HGS fatigability, and lean mass on achievement motivation, peak power, FTP, and maximum oxygen consumption in master's aged triathletes and cyclists.
    - It was hypothesized that maximal HGS, rate of HGS rate of force development, and HGS fatigability, and lean mass will be moderately-to-

strongly correlated with achievement motivation, peak power, FTP, and maximum oxygen consumption in master's aged triathletes and cyclists.

2. Assess differences in maximal HGS, rate of HGS rate of force development, HGS fatigability, and lean mass by achievement motivation, peak power, FTP, and maximum oxygen consumption status in master's aged triathletes and cyclists.
    - The student investigator postulated that maximal HGS, rate of HGS rate of force development, HGS fatigability, and lean mass will be better in master's aged triathletes and cyclists with good achievement motivation, peak power, FTP, and aerobic capacity.
3. Evaluate the concurrent validity of rate of HGS rate of force development and HGS fatigability relative to maximal HGS in master's aged triathletes and cyclists.
    - It was hypothesized that maximal HGS will be moderately correlated with rate of HGS rate of force development and HGS fatigability in master's aged triathletes and cyclists.
4. Examine the criterion validity of rate of HGS rate of force development and HGS fatigability compared to maximal HGS for achievement motivation, peak power, FTP, and maximum oxygen consumption in master's aged triathletes and cyclists.
    - The student investigator postulated that the correlations for rate of HGS rate of force development and HGS fatigability will be stronger and more robust than maximal HGS on achievement motivation, peak power, FTP, and maximum oxygen consumption in master's aged triathletes and cyclists.

Participants

A cross-sectional design was utilized for this investigation. The North Dakota State University Institutional Review Board approved all study protocols. To account for any missing data and adhere to the recommended minimum number of individuals for 80% power in a single group cross-sectional design, the student investigator sought to recruit at least 30 master's aged cyclists and triathletes (Wilson VanVoorhis & Morgan, 2007). The student investigator recruited through word-of-mouth, email list serves, local cycling groups, bicycle shops, bicycle and triathlon community friends, and flyers. Those interested in participating contacted the student investigator to complete a pre-consent screening questionnaire.

To participate in this study, persons were between the ages of 35-70 years (i.e., master's aged cycling or triathlon athlete), and were currently following a triathlon or cycling training program in preparation for a cycling or triathlon race within one-year of study enrollment. Additionally, if participants engaged in a cycling or triathlon race 8-weeks prior to study testing and maintained a training program following the race, they were eligible to participate in the study (Spiering, Mujika, Sharp, & Foulis, 2021). Persons were excluded if they 1) had any musculoskeletal injuries, health conditions, or surgical procedures within the last six months that limit physical functioning, 2) did not own a bicycle, 3) were not ready to participate in physical activity as determined by the PAR-Q+ (Warburton et al., 2011), 4) are not ambulatory, 5) have healthcare provider diagnosed depression, and 6) unable to complete dynamometer testing on both hands due to pain, arthritis, or a surgical procedure. Our study criteria for participation was guided by related risk assessments in older athletes (Moorman, Dean, Yang, & Drezner, 2021). Individuals that have completed eligibility screening were asked to visit laboratories located in

Bentson-Bunker fieldhouse at North Dakota State University. No persons were excluded after implementing screening criteria. The study visit was approximately 90-minutes in duration.

Procedures

Prior to study testing, individuals were asked to avoid strenuous physical activities for 48-hours prior to their visit, and maintain habitual sleeping, eating, and hydration. Persons were advised to visit the lab dressed in their training clothing and bring their personal bike. After completing written informed consent to participate in the study, participants completed a self-report demographics questionnaire asking them about their hand dominance, age, sex, ethnicity, marital status, educational achievement, employment status, cigarette smoking status, alcohol consumption, self-rated health, and if a doctor had ever diagnosed them with the following health conditions: COVID-19, chronic lung disease, heart condition, high blood pressure or cholesterol, psychiatric problems, and diabetes.

Next, participants were asked to complete the Situational Motivation Scale Questionnaire (Appendix A) adapted from Clancy, Herring, and Campbell (2009) and Guay, Vallerand, and Blanchard (2000). This scale was based on the prominent theory of motivation understood from self-determination theory and addresses intrinsic motivation to a task and identified regulation. This scale was modified to meet the athletic domain of the study by stating activity in each question. The scale consisted of eight total questions, four relating to intrinsic motivation and four relating to identified regulation. Each question was scored on a Likert 1-7 scale with 1 indicating; corresponds not at all, and 7 indicating; corresponds exactly. Scores ranged from 8-56 with higher scores representing greater achievement motivation. Persons with “good” achievement motivation had a score greater than the median split of the recorded scores.

Standing height was measured with a stadiometer to the nearest 0.5 centimeter (Health *0* meter, Sunbeam Products Inc., Boca Raton, FL). Body composition and body mass were measured with the InBody 570 (InBody; Cerritos, CA). Body mass index was calculated (kilograms per meters-squared) from measured standing height and body mass. The InBody 570 has been validated for examining body composition and has strong agreement with dual-energy x-ray absorptiometry for evaluating composition in active and non-active populations (Miller, Chambers, & Burns, 2016; Sirirat et al., 2020).

A Biopac handgrip dynamometer (Biopac Systems; Goleta, CA) was used for HGS testing. The Biopac dynamometer allows for force to be digitally recorded in real-time for the duration of a grip task (Park, Baek, Kim, Park, & Kang, 2017). Guidelines for measuring HGS informed our HGS procedures (Roberts et al., 2011). More specifically, participants were comfortably seated with their forearms on the side of a chair, and wrist in a neutral position slightly over the end of the arm of the chair and thumb facing upwards. The student investigator explained, demonstrated, and provided verbal encouragement for all HGS assessments. A practice trial was allowed. Block randomization was used to determine the order of the hands first tested. Two trials were performed for each HGS assessment on both hands with 60-seconds of rest between measures.

During the maximal HGS measurement, participants squeezed the dynamometer with maximal effort, exhaling while squeezing, and then released the muscle contractions. The highest recorded HGS regardless on hand dominance was included in the analyses. Next, RFD was collected by asking the master's athletes to squeeze the hand dynamometer "as fast and as hard as possible for about a second". RFD was calculated as peak force normalized to time (D'Emanuele et al., 2021). The highest performing continuous score was included in the analyses (Maffiuletti, Aagaard, Blazevich, et al., 2016). Thereafter, for the fatigability task, participants were instructed to squeeze the dynamometer with maximal effort for as long as possible. Grip force was collected beginning when the dynamometer is first squeezed until the participant voluntarily released the dynamometer or fatigued to 50% of their maximal HGS (De Dobbeleer et al., 2017). A grip force curve was generated, and fatigue was determined from the fatigability index (Lou, 2012). The lowest recorded fatigability index regardless of hand dominance was included in the analyses.

The anaerobic peak power test was completed after HGS testing. The student investigator fitted the personal bike of each participant and installed the proper cassette to the Tacx Flux S (Garmin, LLC part # T2980.60) indoor direct drive fly wheel trainer. Participants pedaled before any testing for familiarity and comfort. TrainerRoad cycling software (TrainerRoad; Reno, NV) was logged and adjusted to meet the cyclist's personal metrics. Metrics included weight in pounds. A pre-designed bicycle session was created by the student investigator utilizing Training Peaks software (Training Peaks; Louisville, CO). This software allowed the student investigator to pick a specific workload percentage for an individualized time interval for the entire bicycle test. The time interval implemented allowed participants to be able to work at a percentage specific to their individual metrics.

The student investigator then synced the bicycle test from Training Peaks to TrainerRoad and calibrated the trainer. This software was then linked to the Tacx Flux S via Bluetooth. The bicycle test was set to ergonomic mode. In this mode, participants were able to self-select cycling cadence, and the Tacx Flux S trainer automatically worked at a specific resistance at the specific power percentage for each time interval. If the participant chose to increase or decrease their cadence the Tacx Flux S trainer adjusted to meet the power demands. The bicycle session was designed to work at specific percentages to each participant's current training metrics.

Training test sessions were adapted from Dr. Andrew Coggan's peak power protocol, and previous work that has validated the use of peak power sprints prior to completing a maximal fatigue test (Allen et al., 2019; Calbet, De Paz, Garatachea, Cabeza De Vaca, & Chavarren, 2003; Danek, Smolarek, Michalik, & Zatoń, 2020). Participants were warmed-up in ergonomic mode for 15-minutes at 45% FTP until a 4x3-minute build that consisted of ramping-up from 65%, 75%, 85%, and 95%, followed by five more minutes of 45% of FTP easy spinning. Participants were then switched to resistance mode by the student investigator and self-selected gearing was enabled. When in resistance mode the Tacx Flux S trainer allowed the participant to shift bicycle gears and self-select a cadence to mimic real life outdoor road riding. For maximal sprint specific bicycle tests, resistance mode is preferred over ergonomic mode (Allen et al., 2019). Cadence and effort were ramped-up for 10-second maximal sprinting. The highest 5-second peak power reading during the 10-seconds was then recorded and included in the analyses. Moreover, males with peak power ≥12.5 watts/kilogram of body weight and females with peak power ≥9.6 watts/kilogram was considered as having good peak power (Allen et al., 2019). These numbers were determined by the average Category 5 cyclists average for males and females (Allen et al., 2019; www.datacranker.com). Participants were advised to cool down for 15-minutes to recover for the peak power test. This duration of recovery time is adequate to replenish stored intramuscular ATP from anaerobic efforts (Calbet et al., 2003; Danek et al., 2020).

The student investigator instructed the participants about the FTP test during the peak power cool down and fitted them for the VO_2 max data collection. VO_2 max was recorded utilizing the True One 2400 metabolic cart (Parvo Medics, Sandy, UT). Participants were equipped with a headset. This headset only allowed participants to breathe through their mouth and O_2 and CO_2 production was recorded via the Parvo metabolic cart. This test began with 5 minutes of easy spinning at 45% FTP in ergonomic mode on the Tacx Flux S trainer. Following the 5 minutes of 45% FTP spinning, participants experienced an increase of 12-15 watts resistance every 1-minute.

Participants were asked to work at the prescribed incremented power output until they could no longer maintain the prescribed power interval. Resistance increased 12-15 watts every one minute until volitional fatigue. The average maximum one-minute power average was then multiplied by 75% for determining FTP, which was subsequently included in the analyses. Further, male participants with FTP ≥2.7 watts/kilogram of body weight and female participants with FTP ≥2.3 watts/kilogram of body weight was considered as having good FTP (Allen et al., 2019). These numbers were based off Category 5 cyclists (Allen et al., 2019; www.datacranker.com).

During FTP testing, VO_2 was collected at each one-minute interval and established at the one-minute plateau of maximal oxygen consumption recorded. The continuous VO_2 maximum score was included in the analyses. Male participants aged 35-39 years, 40-49 years, and 50-59 years, 60-69 years, and 70-79 years with a VO_2 maximum of 47.0, 44.9, 41.9, 38.3, and 35.2 ml/kg/min were considered as having good aerobic capacity, respectively. Likewise, age-related criteria were used to define female participants with good aerobic capacity: 41.0 ml/kg/min for 35-39 years, 39.2 ml/kg/min for 40-49 years, 35.3 ml/kg/min for 50-59 years, 32.3 ml/kg/min for 60-69 years, and 30.9 for 70-79 years. All age- and sex-specific criteria for determining good maximal oxygen consumption was based on using the 75th percentile from validated normreferenced standards (American College of Sports Medicine [ACSM], 2019). A 15-minute cool down was than completed by all participants to allow time to return to resting central nervous system levels.

Statistical Analysis

SAS 9.4 software (SAS Institute; Cary, NC) was used for analyses. For the overall descriptive characteristics of the participants, continuous data was presented as mean±standard deviation and categorical data was shown as frequency (percentage). To accomplish Purpose 1, individual Pearson correlation analyses determined the relationships of maximal HGS, rate of HGS force development, HGS fatigability, and lean mass on achievement motivation peak power, FTP, and maximum oxygen consumption. Absolute correlation coefficients were used to elucidate the strength of the relationships: <0.10 is negligible, 0.10-0.39 is weak, 0.40-0.69 is moderate, and ≥0.70 is strong (Schober & Schwarte, 2018).

To accomplish Purpose 2, distinct independent t-tests were conducted for assessing differences between maximal HGS, rate of HGS force development, and HGS fatigability, and lean mass by 1) achievement motivation, 2) peak power, 3) FTP, and 4) maximal oxygen consumption status (i.e., good vs. not-good). To complete Purpose 3, Pearson correlation analyses were used to evaluate the concurrent validity between maximal HGS and 1) rate of HGS force development, and 2) HGS fatigability. Absolute correlation coefficients were again used to elucidate the strength of the relationships: <0.10 is negligible, 0.10-0.39 is weak, 0.40-0.69 is moderate, and ≥0.70 is strong (Schober & Schwarte, 2018). For accomplishing Purpose 4, the Pearson correlation coefficients for rate of HGS force development and HGS fatigability relative to maximal HGS on achievement motivation, peak power, FTP, and maximum oxygen consumption were compared. Moreover, these data were ranked, and the same Pearson correlation analyses were again conducted for making comparisons between coefficients.

As supplementary analyses, separate linear regression models were analyzed on the associations of 1) maximal HGS, 2) rate of HGS force development, and 3) HGS fatigability on 1) peak power, 2) FTP, and 3) maximum oxygen consumption after adjusting for age, sex, and body mass index. Individual logistic regression models were used to analyze the association of 1) maximal HGS, 2) rate of HGS force development, and 3) HGS fatigability on 1) good peak power, 2) good FTP, and 3) good maximal oxygen consumption after similarly adjusting for age, sex, and body mass index. An alpha level of 0.05 was used for all analyses.

CHAPTER 4: RESULTS

The descriptive characteristics of the participants are in Table 1. Overall, the 31 participants were aged 49.1±10.4 years, were mostly male (n=23 [74.2%]), but nobody had "good" peak power. A single participant declined participating in aerobic capacity testing. Table 2 shows the results for the correlations of the HGS and lean mass assessments on achievement motivation and cycling measurements (Purpose 1). Maximal HGS was moderately correlated with peak power (r=0.46; p<0.01), while lean body mass was moderately correlated with peak power (r=0.48; p<0.01) and negligibly correlated with aerobic capacity (r=0.37; p=0.04). Rate of HGS force development was also moderately correlated with peak power (r=0.36; p=0.04). There were no other statistically significant correlations observed.

Table 3 presents the differences of the HGS and lean mass assessments by achievement motivation and cycling measurement statuses (Purpose 2). No statistically significant differences existed for the HGS and lean mass variables when dichotomizing aerobic capacity, FTP, and achievement motivation with pre-specified cut-points. Table 4 shows the correlations between the HGS assessments (Purpose 3). Maximal HGS was moderately correlated with rate of HGS force development (r=0.63; p<0.01), but not HGS fatigability (r=-0.04; p=0.79). Moreover, the ranked correlations between the HGS assessments are presented in Table 5. Ranked maximal HGS was moderately correlated with ranked peak power (r=0.40; p=0.02) and ranked lean body mass was moderately correlated with peak power (r=0.50; p<0.01). No other statistically significant ranked correlations existed.

Appendix B shows the associations of the HGS assessments on the continuous cycling measurements (supplementary analyses). No statistically significant associations existed for the HGS assessments and each cycling measurement. Likewise, the associations of the HGS assessments on the cycling measurement statuses are presented in Appendix C. Again, no statistically significant associations were observed for the HGS assessments and cycling statuses.

Table 1. Descriptive Characteristics of the Participants.

	n=31
Age (years)	49.1±10.4
Sleep Time (hours/day)	7.2±0.7
Lean Mass (kilograms)	63.2±13.4
Height (centimeters)	177.7±10.4
Weight (kilograms)	80.2±15.3
Body Mass Index (kilograms per meters-squared)	25.2±3.2
Obesity Status (n (%))	
Obese	2 (6.5)
Not-Obese	29 (93.5)
Motivation	46.1±8.1
Motivation Status (n (%))[¥]	
Higher Motivation	15 (48.4)
Lower Motivation	16 (51.6)
Aerobic Capacity (milliliters per kilograms per minute)[†]	43.6±9.1
Peak Power (watts/kilograms)	5.7±2.2
Functional Threshold Power (watts/kilograms)	2.6±0.5
Maximal Handgrip Strength (kilograms)	34.2±10.6
Rate of Handgrip Strength Force Development (kilograms/second)	73.9±39.7
Ethnicity (n (%))	
Non-Hispanic White	30 (96.2)
Non-Hispanic Other	1 (3.2)
Gender (n (%))	
Male	23 (74.2)
Female	7 (22.6)
Non-Binary	1 (3.2)
Marital Status (n (%))	
Single	8 (25.8)
Married	23 (74.2)
Educational Achievement (n (%))	
Some College or Vocational Training	3 (9.7)
Completed Associate Degree	2 (6.4)

Table 1. Descriptive Characteristics of the Participants (continued)

Completed Bachelor's Degree	12 (38.7)
Completed Graduate Degree	14 (45.2)
Employment Status (n (%))	
Full-Time	26 (83.9)
Part-Time	2 (6.5)
Unemployed	3 (9.7)
Average Hours Trained in Week (n (%))	
<3	7 (22.6)
3-5	16 (51.6)
6-10	8 (25.8)
Persons Living in Household (n (%))	
1	3 (9.7)
2	13 (41.9)
3	5 (16.1)
4	8 (25.8)
5	2 (6.5)
Dominant Hand (n (%))	
Right	30 (96.8)
Left	1 (3.2)
Non-Smokers (n (%))	31 (100.0)
Previous Smoker (n (%))	
Yes	8 (25.8)
No	23 (74.2)
Regular Exerciser (n (%))	
Yes	30 (96.8)
No	1 (3.2)
Consumes Alcohol (n (%))	
Yes	23 (74.2)
No	8 (25.8)
Frequency of Alcohol Consumption (n (%))	
<1-2 days/week	16 (51.6)
1-2 days/week	10 (32.2)
3-4 days/week	3 (9.7)
>4 days/week	2 (6.5)
Self-Rated Health (n (%))	
Excellent	9 (29.0)
Very Good	19 (61.3)

Table 1. Descriptive Characteristics of the Participants (continued)

Good	3 (9.7)
Diabetes Diagnosis (n (%))	
Yes	1 (3.2)
No	30 (96.8)
Other Health Condition Diagnosis (n (%))	
Yes	5 (16.1)
No	26 (83.9)
COVID-19 Diagnosis (n (%))	
Yes	11 (35.5)
No	20 (64.5)
Pain Interference (n (%))‡	
No	25 (80.7)
A Little Bit	4 (12.9)
Moderately	2 (6.4)
Good Aerobic Capacity (n (%))‡	
Yes	11 (36.7)
No	19 (63.3)
Good Peak Power (n (%))	0 (0.0)
Good Functional Threshold Power (n (%))‡	
Yes	7 (23.3)
No	23 (76.7)

¥Based on median split score of 49 points. †n=30 due to participant declining measure. ‡n=30 due to gender reporting.

Table 2. Results for the Correlations of the Handgrip Strength and Lean Mass Assessments on the Achievement Motivation and Cycling Measurements.

	Achievement Motivation	**Peak Power**	**Functional Threshold Power**	**Aerobic Capacity**[†]
Maximal Handgrip Strength	r=0.16; p=0.37	r=0.46; p<0.01	r=0.11; p=0.53	r=0.27; p=0.14
Rate of Handgrip Strength Force Development	r=0.20; p=0.27	r=0.36; p=0.04	r=0.10; p=0.57	r=0.21; p=0.25
Handgrip Strength Fatigability	r=-0.02; p=0.90	r=0.03; p=0.85	r=0.09; p=0.60	r=0.08; p=0.66
Lean Body Mass	r=0.07; p=0.70	r=0.48; p<0.01	r=0.23; p=0.21	r=0.37; p=0.04

[†]n=30 due to participant declining measure

Table 3. Differences of the Handgrip Strength and Lean Mass Assessment by Achievement Motivation and Cycling Measurement Statuses.

	Aerobic Capacity†		
	Good (n=19)	**Not-Good (n=11)**	**p-value**
Maximal Handgrip Strength	32.5±10.1	37.7±11.1	0.20
Rate of Handgrip Strength Force Development	86.6±36.6	68.3±41.2	0.23
Handgrip Strength Fatigability	42.3±24.4	37.9±22.2	0.62
Lean Mass	63.6±64.8	64.8±13.4	0.81
	Functional Threshold Power		
	Good (n=23)	**Not-Good (n=7)**	**p-value**
Maximal Handgrip Strength	36.4±10.1	28.0±10.2	0.07
Rate of Handgrip Strength Force Development	80.7±39.7	66.7±39.8	0.33
Handgrip Strength Fatigability	38.3±23.6	48.5±22.2	0.32
Lean Mass	66.3±11.4	56.4±15.6	0.08
	Achievement Motivation		
	Higher (n=16)	**Lower (n=15)**	**p-value**
Maximal Handgrip Strength	36.0±10.6	32.0±10.6	0.29
Rate of Handgrip Strength Force Development	80.7±42.3	56.1±24.7	0.15
Handgrip Strength Fatigability	45.2±25.7	38.5±22.2	0.44
Lean Mass	63.7±13.7	62.7±13.6	0.83

†n=30 due to participant declining measure

Table 4. Results for the Correlations Between the Handgrip Strength Assessments.

	Maximal Handgrip Strength
Rate of Handgrip Strength Force Development	r=0.63; p<0.01
Handgrip Strength Fatigability	r=-0.04; p=0.79

Table 5. Results for the Ranked Correlations of the Handgrip Strength and Lean Mass Assessments on the Achievement Motivation and Cycling Measurements.

	Achievement Motivation	Peak Power	Functional Threshold Power	Aerobic Capacity†
Maximal Handgrip Strength	r=0.15; p=0.41	r=0.40; p<0.02	r=0.01; p=0.96	r=0.17; p=0.35
Rate of Handgrip Strength Force Development	r=0.20; p=0.27	r=0.26; p=0.14	r=-0.01; p=0.98	r=0.13; p=0.48
Handgrip Strength Fatigability	r=-0.09; p=0.59	r=-0.04; p=0.79	r=0.14; p=0.44	r=0.13; p=0.47
Lean Body Mass	r=0.06; p=0.70	r=0.50; p<0.01	r=0.15; p=0.41	r=0.29; p=0.10

†n=30 due to participant declining measure

CHAPTER 5: DISCUSSION

The principal findings of this dissertation investigation were that maximal HGS was moderately correlated with peak power, rate of HGS force development was moderately correlated with peak power, and that lean body mass was moderately correlated with peak power and negligibly correlated with aerobic capacity in master's aged cyclists and triathletes. When ranking the variables, maximal HGS and lean body mass were each moderately correlated with peak power. Further, rate of HGS force development was moderately correlated with maximal HGS. No other analyses yielded statistically significant findings. When considering the handgrip measures, maximal HGS and rate of HGS force development could be a useful correlate for peak power. While master's aged triathletes and cyclists should continue using traditional human performance tests such as peak power and functional threshold power when possible, maximal HGS and rate of HGS force development may have utility.

A dearth of evidence exists on analyzing the relation between measures of handgrip on cycling and triathlon performance or master's aged athletes (Cronin & Hansen, 2005). Maximal HGS is strongly related to total body strength (Francis et al., 2017; McGrath, Tomkinson, et al., 2021). For human performance, total body strength is considered the ability to produce maximal force in a given output, and is robustly related to aerobic and anaerobic abilities (Cross, Rivière, Coulmy, Morin, & Samozino, 2021). Force and power production is linked to the size and amount of muscle fibers per motor unit (Cross et al., 2021). Cycling performance and testing is measured and valued by generating power production over a given distance. The current dissertation study found moderate correlations between maximal HGS, and peak cycling power. Given that testing peak power on a bicycle requires full body energy expenditure to produce maximal power, assessing HGS may serve as a novel, non-fatiguing test that does not require time away from training, and possibly to predict peak power production in master's cyclists and triathletes. Therefore, continued training allows aging cyclists and triathletes to maintain the cross-sectional area and force production of the muscles of their lower limbs, thereby attributing to consistent training and cycling performance. These findings also suggest that cycling and triathlon training preserves lean mass and strength in aging triathletes and cyclists, preventing age-related losses of physical fitness.

Previous studies have uniquely examined the benefits of HGS in relation to gripping the handlebars while sprinting on a bicycle. For example, a repeated measures study utilizing a randomized cross-over design divided 12 young cyclists into a normal and supinated handgrip group. Cyclists performed the peak sprints on a cycle ergometer rather than their own personal bicycles, thereby creating a more controlled environment. Interestingly, the normal handgrip group had significantly higher cycling peak power output over the non-handgrip group (Baker, Gal, Davies, Bailey, & Morgan, 2001). Similarly, another study utilized a repeated measures design with randomized cross-over on 15 healthy active males to determine the difference in handgrip and non-handgrip on peak power production. This study also measured maximal handgrip prior to testing. The findings from this investigation paralleled those from Davies et al, (2001), showing lower body peak power was significantly related to normal handgrip on a bicycle ergometer. However, this investigation also determined that participants with the highest recorded cycling power outputs showed moderate, positive correlations with maximal HGS measured via handgrip dynamometry. These findings suggest a significant impact of upper body strength during peak power sprinting in cycling and maximal HGS could be related to peak power production in cycling as demonstrated in this dissertation study.

In contrast to the findings of this dissertation investigation, another cross-sectional study examined the relationship between strength and power production in younger trained track cyclists (Vercoe & McGuigan, 2018). Like this dissertation study, the investigators had participants perform a typical warm-up that included easy pedaling with a small ramp in intensity. However, participants underwent a series of isometric hang high strength pulls to measure their maximal strength. There were no significant correlations were observed between maximal strength and peak power production (Vercoe & McGuigan, 2018). Additionally, the participants in this investigation were sprint cyclists. The sample included in Vercoe and McGuigan (2018) underscores that research is lacking on the measure of maximal strength in endurance master's cyclists and triathletes, which further emphasizes the importance of accomplishing this dissertation study.

In comparison, no participants in this dissertation study achieved "good" peak power. Peak power was determined as "good", by reading the highest 5-second peak power reading during the 10-seconds sprint. Moreover, males with peak power ≥12.5 watts/kilogram of body weight and females with peak power ≥ 9.6 watts/kilogram will be considered as having "good" peak power (Allen et al., 2019). The absence of persons with "good" peak power in this dissertation study could be explained by a few factors. First, stationary smart trainers have some limitations involving sprinting mechanics. Typically, when sprinting outdoors, the cyclist shifts the bicycle underneath him from right to left. This increases the lever during the pedal stroke to create a greater torque, thus, greater power output and sprinting speed. On a stationary smart trainer, the trainer itself serves as the rear wheel in indoor biking situations. Additionally, the stationary smart trainers are built to be robust and durable, the cyclist cannot shift the bicycle from right to left underneath them, causing him or her to change their sprinting mechanics, which may alter peak power production (McIlroy et al., 2021).

Moreover, some reviews have proposed a slight delay within the smart trainer when reading various maximum sprints. A particular review that examined the safety, strengths, and weaknesses of indoor bicycle riding found that the model and age of the trainer may affect the rate at which power is received (McIlroy et al., 2021). Lastly, the firmware update may affect the power reading performance. The current dissertation investigation utilized an above average and fully updated smart trainer for the purposes of data collection, but this limitation may have affected the overall peak power scores.

This dissertation study also determined moderate correlations on cycling peak power production and handgrip RFD. Peak power is a measurement of the amount of work completed, or force over a given displacement divided by the time at which it is applied. More simply, peak power is the amount of work you can produce in the shortest time. RFD is the time it takes to achieve maximum force output. Therefore, the mechanics of these two measures are mechanically similar and the findings of this study suggest that the rate at which we can produce force in our handgrip is like the rate at which we can apply force in cycling over time.

Peak power output was also moderately correlated with lean body mass in master's aged cyclists and triathletes that participated in this dissertation study. Two major components of skeletal muscle that are highly related to force production in performance are, the size of the muscle fiber and the ability to recruit large motor units (Maciejczyk, Wiecek, Szymura, Szygula, & Brown, 2015). Lean body mass is the amount of skeletal muscle mass an individual's body comprises and is highly related to athletic performance. In performance tests measuring peak anaerobic power, performance is typically measured in relation to body mass, such as watts per kilogram. There is a direct positive relationship for total lean body mass and power production in anaerobic outputs (Maciejczyk et al., 2015). Cycling and triathlon are also endurance sports that require lower levels of overall body fat to reduce the mass carried throughout the entire endurance event. For example, a cross-sectional study examined 36 young male cyclists on the effect lean body mass alone, fat mass alone, and lean body mass and fat mass had on peak power production. These investigators found that, in general, there were moderately positive correlations in peak power production with increased body mass. Further, participants with high lean body mass showed stronger positive correlations for peak power output (Maciejczyk et al., 2015). These findings are in alignment with the findings of the current dissertation study suggesting lean body mass had a positive correlation with peak power output.

This dissertation study had some limitations. Participants were instructed to retain regular eating and training habits, which was based on self-report. A single participant declined aerobic capacity testing, while another participant identified as having a non-binary gender, which led to this person being excluded from sex-specific performance categories. Accordingly, an additional participant was recruited to meet the sample size proposed. RFD was calculated as peak force normalized to time, which is the most used method of calculating RFD, but other methods for calculating RFD exist (D’Emanuele et al., 2021; Maffiuletti, et al., 2016). While the electronic handgrip dynamometer is valid for measuring isometric grip force, reliability metrics are absent, albeit reliability is likely strong. Participants completed cycling testing on their own bicycle, and therefore, differences in equipment across participants may have influenced the measures. There is a potential ceiling issue with analysis of the motivation questionnaire as all participants are assumed to be highly motivated. A cross-sectional design was utilized for this work, thereby limiting temporal trends.

Undeniably, the master's aged athletes competing in triathlon and cycling will continue growing. Continued research on methods to predict current triathlon and cycling performance for the aging athlete are warranted. Handgrip RFD and maximal HGS correlate with peak power production. Therefore, research should be compared with other maximal muscle strength tests in aging cyclists and triathletes, such as, isometric hang-high pull, dead lift, and squat. These maximal strength tests have been related to power production and lean body mass in cyclists (Caserotti, Aagaard, & Puggaard, 2008). Additionally, investigations considering maximal HGS on different hand positions on a road and triathlon bike may contribute to exercise economy as maximal HGS was related to sprinting capabilities in cyclists (Baker et al., 2001). This continued research may allow for increased adherence to training programs.

Conclusion

Maximal HGS and handgrip RFD positively and moderately correlates with peak power sprinting in master's aged cyclists and triathletes. Greater lean body mass also contributed to higher peak power production. Due to training time implications, adherence to a cycling training program is needed to maintain maximal aerobic capabilities, power production, and lean body mass. The findings of this dissertation study may allow for coaches and athletes to use a feasible human performance assessment tool, continue cycling and triathlon training programs without additional rest days from maximal performance tests. Maximal HGS and rate of handgrip RFD show promise for being utilized in a single protocol as a correlate for peak power when such testing is not available when training time is limited. Lastly, maintaining lean mass is also advised for human performance in older endurance athletes to maintain force production and performance.

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APPENDIX A. RESULTS TABLE FOR CONTINUOUS CYCLING MEASUREMENTS

Table A1. Results for the Associations of the Handgrip Strength Assessments on the Continuous Cycling Measurements

	Peak Power		
	β	**95% Confidence Interval**	**p-value**
Maximal Handgrip Strength	0.06	-0.03, 0.16	0.21
Rate of Handgrip Strength Force Development	0.01	-0.01, 0.02	0.57
Handgrip Strength Fatigability	0.01	-0.01, 0.04	0.39
	Functional Threshold Power		
	β	**95% Confidence Interval**	**p-value**
Maximal Handgrip Strength	-0.01	-0.02, 0.01	0.53
Rate of Handgrip Strength Force Development	-0.01	-0.01, 0.01	0.34
Handgrip Strength Fatigability	0.01	-0.01, 0.01	-0.48
	Aerobic Capacity[†]		
	β	**95% Confidence Interval**	**p-value**
Maximal Handgrip Strength	-0.01	-0.35, 0.33	0.93
Rate of Handgrip Strength Force Development	-0.01	-0.08, 0.04	0.60
Handgrip Strength Fatigability	0.04	-0.05, 0.14	0.33

[†]n=30 due to participant declining measure. *Note*: Models were adjusted for age, gender, and body mass index.

APPENDIX B. RESULTS TABLE FOR CYCLING MEASUREMENT STATUSES

Table B1. Results for the Associations of the Handgrip Strength Assessments on the Cycling Measurement Statuses.

	Functional Threshold Power		
	Odds Ratio	**95% Confidence Interval**	**p-value**
Maximal Handgrip Strength	0.91	0.63, 1.31	0.63
Rate of Handgrip Strength Force Development	0.99	0.95, 5.76	0.81
Handgrip Strength Fatigability	1.00	0.93, 1.08	0.86
	Aerobic Capacity[†]		
	Odds Ratio	**95% Confidence Interval**	**p-value**
Maximal Handgrip Strength	1.06	0.92, 1.22	0.38
Rate of Handgrip Strength Force Development	1.01	0.98, 1.04	0.22
Handgrip Strength Fatigability	1.00	0.96, 1.04	0.86

[†]n=30 due to participant declining measure. *Note*: Models were adjusted for age, gender, and body mass index.

APPENDIX C. IRB APPROVAL LETTER

NDSU NORTH DAKOTA STATE UNIVERSITY

04/22/2022

Dr. Ryan McGrath
Health, Nutrition & Exercise Sciences

IRB Approval of Protocol #IRB0004196, "Using Electronic Handgrip Dynamometry to Determine Human Performance in Master's Aged Cyclists and Triathletes".

Co-investigator(s) and research team:

- Ryan McGrath
- Lukus A Klawitter
- Madison Patrick
- Nellie Masseth
- Sarah Andrew

Approval Date: 04/22/2022
Expiration Date: 04/21/2023
Research site(s): BBFH 6, 14, 15, and 110F
Funding Agency:
Review Type: Expedited category # 4

The above referenced protocol has been reviewed in accordance with federal regulations (Code of Federal Regulations, Title 45, Part 46, *Protection of Human Subjects*).

Additional approval from the IRB is required:

- Prior to implementation of any changes to the protocol.
- For continuation of the project beyond the approval period. A task will automatically generate for the PI and Co-PI 8 weeks prior to the expiration date. To avoid a lapse in approval, suspension of recruitment, and/or data collection, a report must be received, and the protocol reviewed and approved for continuation prior to the expiration date.

Other institutional approvals:

- Research projects may be subject to further review and approval processes.

A report is required for:

- Any research-related injuries, adverse events, or other unanticipated problems involving risks to participants or others within 72 hours of known occurrence.
- Protocol Deviations.
- Any significant new findings that may affect risks to participants.

Thank you for cooperating with NDSU IRB procedures, and best wishes for a successful study.

NDSU has an approved FederalWide Assurance with the Department of Health and Human Services: FWA00002439.

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