2D:4D FINGER RATIO IN CROSSFIT ATHLETES

by

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ABSTRACT

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The second digit and fourth digit (2D:4D) finger ratio is known to be an indicator of *in utero* androgen influence. Here, I review current research concerning 2D:4D ratio, particularly in regards to muscle strength, muscle mass, and athletic ability. Studies on athletes have shown a significant negative correlation between the ratio and athleticism and an inconsistent correlation with muscle mass and muscle strength. I propose a research study on the relationship between the 2D:4D ratio and Crossfit athletes and its relationship to muscle mass and muscle strength.

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BACKGROUND

The relationship of the index and ring finger is the (2D:4D) digit ratio, and is an important biomarker of sexual orientation. Prenatal androgen and estrogen exposure at birth determines this ratio and is fixed as early as the second trimester in the womb (Lutchmaya et al., 2004; Malas et al., 2006). 2D:4D ratio does not change during puberty or throughout the adult life (Garn et al., 1975; Trivers et al., 2006).

The most significant and universal finding in almost every 2D:4D ratio study is the correlation with gender; 2D:4D ratio is sexually dimorphic, indicating that a lower ratio reflects higher *in utero* androgen exposure (males) and a higher ratio reflects higher *in utero* estrogen exposure (females). The 2D:4D ratio is likely a balance between the prenatal testosterone and estrogen because the fetal fourth digit has a large number of androgen receptors (Manning, 2011).

Because of the sexual dimorphism in the 2D:4D ratio and the strong correlation between the ratio and sex hormone exposure, 2D:4D in adults is a reliable measure of the amount of testosterone the individual was exposed to during prenatal stages (Zheng & Cohn, 2011). Prenatal testosterone exposure has numerous long-term effects on the body, including regulation of skeletogenic genes, brain, and physiological systems (e.g., cardiovascular and endocrine systems) (Dyer et al., 2017; Kimura, 1996; Mortlock & Innis, 1997; Zheng & Cohn, 2011). Prenatal testosterone and estrogen impact the expression of the

SPARC-related modular calcium binding 1 (SMOC1) gene; androgen exposure causes an up-regulation of SMOC1 transcript, whereas, estrogens exposure causes a down-regulation (Coleman et al., 2006; Love et al., 2009; Schaeffer et al., 2008). SMOC1 has diverse functions, including regulation of the development of cartilage in the digits. The strong regulation of SMOC1 by androgens and the critical role the gene serves in modulation of digit development has lead to a widely supported hypothesis that correlation of 2D:4D between males and females may be controlled by regulation of SMOC1 (Bradshaw, 2012; Choi et al., 2010; Lawrance-Owen et al., 2013; Stricker & Mundlos, 2011; Vannahme et al., 2002).

Sex-dependent differences in 2D:4D ratio were first discovered in 1983 by Dr. Glenn D. Wilson (Wilson, 1983 and reviewed in 2010). Since then, researchers have examined the relationship between the ratio and a wide range of pathological and physiological traits (Table 1). For example a lower ratio is strongly correlated with increased athletic ability in both women and men across a variety of sports (Giffin et al., 2012; Kim & Kim, 2016; Manning, 2002; Voracek et al., 2010).

Table 1: Physiological and Pathological Traits Correlated to 2D:4D Ratio

Trait Studied	**Low 2D:4D Ratio**	**High 2D:4D Ratio**	**Source**
Sperm Counts	Higher counts	Lower counts	Manning et al., 1998
Prostate Cancer	Higher incidence	Lower incidence	Jung et al., 2011
Neck Circumference	Lesser circumference	Greater circumference	Fink et al., 2006
Coronary Heart Disease	Lower risk	Higher risk	Fink et al., 2006
Athletic Ability	Greater ability	Lesser ability	Dyer et al., 2017; Hsu et al., 2015; Manning & Taylor, 2001; Moffit & Swanik, 2011

Researchers also studied different psychological disorders and behavioral traits and their relationship to 2D:4D ratios (Table 2). A lower 2D:4D ratio has been correlated with improved performance on the Mental Rotation Test (MRT) which measures visual-spatial ability (Peters et al., 2007). Geschwind and Galaburda (1985) suggested that high prenatal testosterone promotes the growth of the right hemisphere of the brain which facilitates visual-spatial ability. Studies have found that athletes score higher on the MRT than non-athletes (Manning & Taylor, 2001; Moreau et al., 2011).

Table 2: Psychological and Behavioral Traits Correlated to 2D:4D Ratio

Trait Studied	Low 2D:4D Ratio	High 2D:4D Ratio	Source
Depression	Lower incidence in men	Higher incidence in men	Bailey & Hurd, 2005
Schizophrenia	Lower incidence in men	Higher incidence in men	Collinson et al., 2010
Alcohol Dependency	Higher incidence	Lower incidence	Kornhuber et al., 2011
Aggression	Higher incidence in men	Lower incidence in men	Hönekopp & Watson, 2011
Mental Rotation Test (MRT)	Improved performance	Decreased performance	Peters et al., 2007

Muscle Strength and Muscle Mass

Androgen hormones promote protein synthesis and have anabolic properties that stimulates development and growth of muscle mass (MM), muscle strength (MS), bone density, bone strength (Sheffield-Moore, 2000). Studies have generally linked a low 2D:4D ratio to increased strength, but the evidence is inconclusive as strength is also influenced by mass, testosterone, and behavioral factors (Ribeiro et al., 2016). Folland et al. (2012) found that the correlation between the 2D:4D ratio and sports performance was not dependent on MS. However, Halil et al. (2013) found a significant negative correlate with MM and MS in elderly patients (65 years or older). Other studies have since shown inconsistent correlations between the 2D:4D ratio and MM and MS. Loss of MM (sarcopenia) and MS occurs with aging and increases the risk of physical disability, poor quality of life and death (Cruz-Jentoft et al., 2010). There are multiple factors that decrease MM and MS which is not completely understood (Bastiaanse et al., 2012; Halil et al., 2013; Muscaritoli et al., 2010). One example includes levels of testosterone, which decrease with age. In turn, reduced testosterone levels cause a decrease in both mass and strength over time (Feldman et al., 2002; Morley et al., 2011). If the 2D:4D ratio could be correlated unequivocally to MM and MS, then the use of the ratio could be used as a supplementary tool in every day medical practice to diagnose diseases like sarcopenia. Research is limited on this relationship and should be examined further.

Athletes and 2D:4D Ratio

Numerous researchers have examined whether 2D:4D ratios correlated with strength and athleticism (Manning et al., 1998; Manning & Taylor, 2001). Manning and Taylor (2001) performed the earliest study on English professional football (soccer) players of different league divisions. In the study of 304 athletes, they found a lower ratio in English football players versus non-athlete controls. The 2D:4D ratios among groups, from highest to lowest, were:

competitive international players, coaches, premier club players, division club players, and non-athletes (Manning & Taylor, 2001). Comparing different athletes from sports, Moffit & Swanik (2011) found the rank order of lowest to highest 2D:4D ratios were: football, gymnastics, and rowing (Moffit & Swanik, 2011). Research has suggested the 2D:4D ratio may reflect short-term activation effects of testosterone. A low ratio is correlated with hormonal responses during physical and aggressive challenge situations, repeated cycle sprint test or aggressive videos, in adult men (Crewther et al., 2015). Ribeiro et al. (2016) suggested that this correlation explains the 2D:4D ratio association to sports performance, but there are numerous studies on various sports (i.e. football, basketball, soccer, gymnastics, and tennis) that show a negative correlation with performance.

Studies on female athletes have also found similar results. Pokrywka et al. (2005) found elite female athletes that have a significantly lower 2D:4D ratio compared to the control group (non-athletes). The most recent study on female semi-professional basketball players concludes that "female players with lower digit ratios tend to perform better in several aspects of basketball, especially defensively, and were more likely to be starters, suggesting they are the best players on the team in their positions" (Dyer et al., 2017). Female fencers who participate in the most aggressive form of fencing, the sabre, are found to have a lower 2D:4D ratio than those active in other less aggressive forms (Voracek et al., 2010).

Taken together, these data suggest one main point: athletic success may be prenatally programmed, and a consequence of the long-term effects of testosterone exposure *in utero*. Moreover, because the 2D:4D ratio remains constant throughout the human lifespan, athletic performance may be affected only marginally by current androgen and estrogen levels (Trivers et al., 2006). "These results…reflect the organizational benefits of prenatal testosterone"(Dyer et al., 2017) and leads us to the main question of this literature review of whether Crossfit athletes would produce low 2D:4D ratio results.

Crossfit and 2D:4D Ratio

Crossfit is a unique because it merges many sports into one. It can be described as a form of high-intensity interval training (Milanović et al., 2015) or as founder Greg Glassman (2007) wrote, a "constantly varied, high-intensity, functional movement." It is a relatively new sport that first appeared in 2000, but has grown fast, and is now widespread throughout the world. Crossfit was originally designed to train people in the military and police forces who require regular physical fitness to prepare for unknown situations (Meyer et al., 2017). Greg Glassman (2007) intended to "build a program that would best prepare trainees for any physical contingency [and] prepare them not only for the unknown but the unknowable." Crossfit incorporates functional movements to promote MS and cardiovascular fitness (Weisenthal et al., 2014). These functional movements include, but are not limited to, Olympic lifting (e.g., squats, cleans, deadlifts, bench press, and presses), gymnastics (e.g., pull-ups, lunges, knees to elbows, handstand pushups, push-ups, and sit-ups), and aerobic exercise/metabolic conditioning (e.g., swimming, running, and rowing)(Longe, 2012; Weisenthal et al., 2014). Ribeiro et al. (2016) suggested that the 2D:4D ratio is negatively correlated to strength in challenge situations, short term hormonal responses to aggressive challenge situations. To date, no studies have examined the relationship of the 2D:4D ratio and Crossfit performance. Due to the high-intensity training, it is plausible that Crossfit athletes will have a low 2D:4D ratio, but no study has directly tested this hypothesis.

PURPOSE OF PROPOSED RESEARCH

The purpose of this research proposal is to understand the relationship between the 2D:4D ratio with Crossfit athletes and MM and MS from three independent studies. The first study will analyze the relationship between performance of male and female Crossfit athlete's in Crossfit activities and their 2D:4D ratio. The second study will evaluate differences in 2D:4D ratios of competitive athletes versus non-competitive Crossfit athletes. A third study will measure the MM and MS of all the above individuals to examine further the relationship between 2D:4D ratio and MM and MS. For this proposed study, competitive Crossfit athletes are defined as individuals who perform Crossfit exercise in competitions, such as the Crossfit Regional or World competitions. Non-competitive Crossfit athletes would ideally perform Crossfit workouts 2-3 times weekly. I hypothesize a lower 2D:4D ratio in Crossfit athletes versus non-athletes, a lower ratio between competitive athletes versus non-competitive Crossfit athletes and a possible negative correlation with MM and MS.

METHODOLOGY

For this research study, I would use a cross-sectional design where data is taken from the population during a specific time frame. This experimental design is appropriate because the 2D:4D ratio is a constant measurement. Three groups would be tested during this study; each individual would be tested once.

Participants

The study population would consist of three groups: competitive Crossfit athletes, non-competitive Crossfit athletes, and a non-athletic control group. Ideally, the study should include more than 30 individuals of each group in order to ensure statistical accuracy and consistency. The participants should be between the ages of 21 to 35 years, the prime ages of muscular development, and cannot have or had any form of hand injury in their lifetime as this can affect the 2D:4D ratio.

2D:4D Ratio Measurement

The 2D:4D ratio should be measured directly by digital caliper, the most accurate system proposed by Ribeiro et al., (2016). The second digit and fourth digit should be measured on the right and left hands from the mid-point on the ventral flexion crease to the tip of the finger the digital caliper with 0.01mm precision. A longer index finger yields a higher ratio and a longer ring finger yields a lower ratio. To calculate the 2D:4D ratio the following formula should be used: 2D:4D ratio $= \frac{Length\ of\ the\ Second\ Digit\ (mm)}{Length\ of\ the\ Fourth\ Digit\ (mm)}$.

Muscle Mass Measurement

Calf circumference and a bioimpedence scale should be used to measure the muscle mass (MM) with participant in the standing position (Halil et al., 2013). The anthropometric tape should be used to wrap around the dominant calf, without compressing subcutaneous tissue (Halil et al., 2013). If the participant does not know whether they have a dominant versus non-dominant leg for sports then the right calf should be measured. A bioimpedence scale measures several body indicators (body mass index, body fat percentage, skeletal muscle, and body weight) that will go into the calculation of MM. Bioimpedence measures can be performed on most individuals because the signal is undetectable and harmless, but should not be used on individuals with a pacemaker or other electronic medical devices (Omron Healthcare Inc., 2009). To calculate MM, the participants would step onto the bioimpedence scale (model: Ormon HBF-510W Body Composition Monitor with Scale) to measure the indicators listed above. It estimates body composition by measuring the body's ability to conduct a 500-800 microamp, 50 kilohertz, electrical current (via footpad sensor) that runs through the water of muscle and fat tissue. Lean body mass, fat mass, and MM can be calculated from the differences in electrical currents through the different fluid and tissue types (Dehghan & Merchant, 2008).

Muscle Strength Measurement

Muscle Strength (MS) should be measured by evaluating the handgrip strength in both dominant and non-dominant hands with the use of a hand dynamometer. A dynamometer is an instrument that measures the grip strength (in ohms) of the muscles of the arm and hand. To use it, the participant will stand or sit with their arm by their side and elbow flexed to 90 degrees while squeezing the handgrip of the dynamometer as tight as possible. This is known as an isometric muscle contraction. The participant will then squeeze the grip three times with each hand and the mean value for each hand should be recorded as their MS.

DISCUSSION

The results of this study are entirely theoretical at this point in time. Performing this study would add to the growing research on the link between the 2D:4D ratio and specific athletic groups and the limited research on the link between the 2D:4D ratio and MM and MS. If a negative correlation is found between competitive Crossfit athletes and non-competitive athletes, then the ratio could potentially be used as an indicator of athletic ability in the sport. If significant correlations are found between the 2D:4D ratio, MM, and MS, health professionals could potentially predict susceptibility of MM and MS loss based on the pre-natal androgen correlation to the ratio. It is a inexpensive and easy measurement process to administer to test for diseases that are related to MM and MS. This literature review encourages the execution of this proposed research study along with further research to draw conclusions regarding the true extent of relationships between the 2D:4D ratio, Crossfit athletes, MM and MS.

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