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Psychometric analysis and dimensionality of mental toughness in the context of judo performance

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1 Abstract

In recent years, much progress has been made in the field of mental toughness research. Today most researchers can agree on a common base when defining mental toughness, but there are still some conceptual ambiguities and inconsistent operationalizations. The purpose of this study was to shed some light on differences and similarities between mental toughness questionnaires, namely the MTQ48, the SMTQ, and the TROSCI. The concept of mental toughness was explored in the context of performance in judo. In addition, 2D:4D digit ratio, a putative marker of prenatal testosterone, and hand-grip strength, which are both presumed to be related to sports performance, were investigated. Self-reported aggression was also included in this study, as this personality trait might be especially martial arts-related. Data were collected from a sample of 140 Austrian judo athletes. The psychometric quality of the three mental toughness questionnaires, which was assessed with factor analysis, seems to require further development and modification. The questionnaires and subscales need revision to improve their convergent and discriminant validity. Mental toughness showed a significant relation to judo experience and both variables were strongly and negatively correlated with aggression. 2D:4D was unrelated to any of the examined variables, except for BMI. Hand-grip strength displayed a negative relationship with aggression and some relation to training intensity. A dominance analysis model predicting sporting success indicated that following experience and training, mental toughness and self-esteem are the most important variables with hand-grip strength being the third most important factor.

2 Zusammenfassung

In den vergangen Jahren wurden auf dem Gebiet der Mental Toughness Forschung große Fortschritte verzeichnet und es gibt heute ein paar grundlegende Definitionen, denen die meisten Forscher zustimmen. Trotzdem stellt vor allem die Messung noch immer große Schwierigkeiten dar, und verschiedene Konzepte führen zu uneinheitlicher Operationalisierung. Der Zweck dieser Studie war es, zu größerer Klarheit über die Unterschiede und Gemeinsamkeiten von drei Mental Toughness Fragebögen beizutragen (MTQ48, SMTQ, TROSCI). Die Ergebnisse wurden in Zusammenhang mit Erfolg im Judosport erhoben und auch körperliche Variablen wie das 2D:4D Fingerlängenverhältnis sowie die Handgriffstärke. Zusätzlich wurde Aggression als Persönlichkeitsmerkmal in Zusammenhang mit Kampfsport untersucht und diskutiert. Die Stichprobe bestand aus 140 Österreichischen Judokämpfern und -kämpferinnen. Die psychometrische Qualität der Mental Toughness-Fragebögen wurde mittels Faktorenanalyse beurteilt. Es zeigte sich Bedarf an weiterer Überarbeitung und Übereinstimmung der verschiedenen Messinstrumente, vor allem in Bezug auf die konvergente und diskriminante Validität der Fragebögen und der einzelnen Skalen. Mental Toughness wies außerdem einen signifikanten Zusammenhang mit Erfahrung im Judo auf und diese beiden Variablen waren stark negativ mit Aggression korreliert. Für das 2D:4D Verhältnis konnten keine Zusammenhänge mit den anderen Variablen abgesehen von BMI gefunden werden. Die Handgriffstärke zeigt dagegen eine stark negative Beziehung zu Aggression und eine leicht positive zur Trainingsintensität. Bei der Vorhersage sportlichen Erfolgs durch die anderen Variablen mit einer Dominanzanalyse konnte festgestellt werden, dass neben Training und Erfolg vor allem Mental Toughness und Selbstwert sowie die Handgriffstärke ausschlaggebend waren.

3 Introduction

Since it became an Olympic discipline in 1964, judo has attracted millions of athletes from around the world. Children and adults alike have been attracted by its principle of being a “gentle” martial art, where kicking or punching is forbidden in competition (Österreichischer Judoverband, 2012). Apart from being a popular sport, professional judo has also developed into a profitable business for world-class athletes. To date four Austrian judo athletes have won medals at the Olympic Games (International Olympic Committee, 2012):

- Josef Reiter: 1984, bronze medal
- Peter Seisenbacher: 1984, 1988, 2x gold medal
- Claudia Heill: 2004, silver medal
- Ludwig Paischer: 2008, silver medal

These accomplishments place Austria at number 13 in the Olympic judo medal table. This is especially impressive, considering that, to date, judoka (practitioners of judo) from 50 nations representing all six continents have won Judo medals at the Summer Olympics (International Olympic Committee, 2012).

Compared to other sports, judo has always had a more holistic training philosophy, focusing equally on physical and mental strength. This mindset is best summed up by Jiichi Watanabe and Lindy Avakian (1960), who stated that, “in regard to a judo expert’s level of mental development, the arms are an extension of the mind” (Watanabe & Avakian, 1960, p. 18).

Over the past few years, many other sports have discovered the benefits of mental development, and the phrase “mental toughness” has become one of the most frequently used but least understood terms (Sheard, 2010). Despite being associated with success in numerous sports, past mental toughness research has focused too much on qualitative definitions and interviewing athletes in place of quantitative studies (Crust, 2008).

When it comes to measuring mental toughness, there are indications that even identically-named mental toughness scales are measuring different things (Crust & Swann, 2011). Addressing concerns regarding the psychometric quality of mental toughness assessment tools will be one of the core tasks of this study. Judo, as a martial art with an emphasis on mental toughness, is well-suited as a

tool to investigate this assumption. Judo can also be used to study associations between mental toughness and self-esteem or aggression – the latter being a particularly popular personality trait in connection with martial arts (for an overview, see Vertonghen & Theeboom, 2010).

In addition to mental strength, physical fitness and ability are the other important factors necessary for victory in any sport (Sheard, 2010). This study focuses on measuring two non-invasive putative markers of prenatal testosterone. The first one of these is the 2D:4D digit ratio and the other is hand-grip strength (HGS). Manning, Bundred, and Taylor (2003) found connections between sporting ability and 2D:4D for middle- and long-distance running speed and football. This also holds true for fencing, where the connection remained significant even after taking the effect of weight, experience and training intensity into account (Voracek, Reimer, & Dressler, 2010).

As hand-grip strength is an easy way to measure physical health and muscle function, it has been used by a wide range of researchers such as epidemiologists, gerontologists, and even evolutionary psychologists (Gallup, White, & Gallup, 2007). This study focuses on the potential relationship between HGS and 2D:4D following published results (Fink, Thanzami, Seydel, & Manning, 2006) and also on the effects of HGS on success in judo.

The introduction provides basic information about judo as well as an overview on mental toughness concepts and definitions. Subsequently, results from the latest research on mental toughness, aggression, digit ratio, and hand-grip strength are presented. Then a description of the present study's hypotheses is given, followed by information on the methods that were used for the analysis. The next section lists the results with reference to the hypotheses. Finally, the obtained results are discussed in the light of former research, critically analyzing the limitations of the study and also discussing further implications for future work.

3.1 Theoretical Background

3.1.1 Judo

Kodokan judo is a martial art developed from jiu-jitsu around 1882 by Japanese Jigoro Kano. The word judo is made up of the Japanese words “JU” meaning gentle and “DO” meaning way, so judo is often translated as “the gentle way”. The categorization of Kodokan judo was completed about 1887. The Kodokan had three main goals: physical education, contest proficiency and mental training (Österreichischer Judoverband, 2012).

The most important principle is to win by utilizing the opponents attack and to exercise an efficient use of balance, leverage and movement. Skill, technique and timing, will lead to success in judo rather than the use of brute strength. Judo is a dynamic combat sport that demands both excellent physical abilities and mental discipline. From a standing position, there are many techniques to lift and throw opponents onto their backs. When fighting on the ground, there are several different kinds of techniques which consist of pinning opponents down to the ground, controlling them, and applying various chokeholds or joint locks until the opponent gives in (International Judo Federation, 2012).

Unlike karate, aikido or kendo, judo does not involve kicking, punching, or striking techniques of any kind. Pressure against the joints to throw an opponent or equipment or weapons of any sort are also not used in judo. Instead, judoka grip their opponent’s uniform, or “judogi”, using balance, power, and movement to subdue the other person (International Judo Federation, 2012). Although rules change constantly there are four general goals which judoka always try to comply with (International Judo Federation, 2007b). These are the safety of the contestants, the equality of capabilities of the contestants, the preservation of judo traditions and technical specificity and the improvement of attacking judo.

Judo was introduced to the Olympic Games in 1964 and is practiced by millions of people throughout the world today. At competitions men and women have separate contests and there are several weight divisions within every age group. As for the numbers of participants worldwide, judo is second only to soccer. Regarding the number of member nations in the IJF (International Judo

Federation), judo is the largest sport in the world (International Judo Federation, 2012).

Judo is a very demanding sport. Practicing judo techniques helps people to develop strength, flexibility, agility, speed, balance, explosive power, and endurance. It also helps to develop reaction time, coordination, and overall physical self-confidence (International Judo Federation, 2012).

Achievement in judo is recognized in two ways. One is the level on which athletes compete in competitions (i.e., state or country wide or international tournaments) the other one is the judo rank system. Athletes wear belts of different colors that show their level of skill. The ranking system in judo is based on the “kyu” and “dan” grades. The dan grades are the more advanced belts, and they are signified by wearing a black belt. High dan grades from 6th to 8th dan can also wear a checkered red-and-white belt instead of the black belt, 9th and 10th dan holders can wear a red belt (International Judo Federation, 2007a).

The kyu grades are always non-black belt colors. The original judo developed in Japan included 6 kyu ranks. Today however, each country has its own ranking system with different numbers of kyu ranks and belt colors. The only similarity across countries and organizations is that all beginners begin at white belt, and all dan holders wear a black belt (International Judo Federation, 2007a). Kyu ranks go backwards as rank increases, dan ranks, however, go up. Black belts (1st to 5th Dan) can be obtained through mastery of different judo techniques, as opposed to 6th to 10th which can only be awarded by a judo association for special achievements.

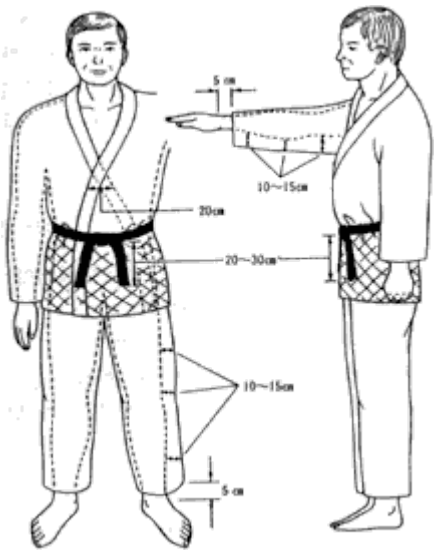

Figure 1 Rules for the fit of a competition judogi, Source: http://judoinfo.com/gi11.gif

If judoka want to compete internationally, their judogis have to comply with strict standards (Ohlenkamp, 2001). They are usually made of cotton and they must not be hard or slippery so the opponent can grip them. The jacket has to cover the thighs and the sleeves should reach the fists when the arms are extended. The trousers should reach to the ankle joint and legs as well as arms should have a

space of 10-15 centimeters between the trousers/sleeves and the legs or arms, respectively. A strong belt has to be worn over the jacket around the waist and it is tied with a square knot tight enough to prevent the jacket from hanging loose. It has to be long enough to go twice around the waist. In addition, female contestants have to wear a white short sleeved t-shirt under the jacket (Ohlenkamp, 2001).

Since most martial arts were predominantly male sports for a long time, women who wanted to practice judo were discriminated against for the first half of the 20th century. The first women's World Judo Championships took place in New York in 1980 and women were allowed to compete for the first time in the 1992 Summer Olympics. Sport participation rates vary, but currently, women represent roughly twenty percent of most color belts and about ten percent of black belts (International Judo Federation, 2007c).

Franchini, Del Vecchio, Matsushigue and Artioli (2011) provide an extensive overview of physiological profiles of successful judo athletes. In short, it can be said that judo is a dynamic, high-intensity sport with frequent interruptions, requiring the athletes to master complex skills and have a robust tactical knowledge for success. The most distinguishing features of successful judoka are very low levels of body fat (except for heavy-weight athletes), highly developed dynamic strength, muscular endurance, and power and capacity in both aerobic and anaerobic regimes. It should be noted however that aerobic power and capacity are not as well-developed as in athletes from other sports. Also, the lower body of judoka seems to be better developed than the upper body when it comes to muscle power. Despite the fact that gripping an opponent’s uniform is a prominent feature of judo, isometric grip strength is only slightly above the average of the non-athlete population, and not significantly correlated with success (Franchini, Miarka, Matheus, & Del Vecchio, 2011; Franchini, Takito, Kiss, & Sterkowicz, 2005; Sanchez, Dominguez, Turpin, Tormo, & Llorca, 2011). It seems that grip endurance is more important than grip strength for judoka (Franchini, Miarka et al., 2011).

3.1.2 Mental Toughness

Despite the fact that the term “mental toughness” is one of the least understood terms in sport psychology, it is widely used by coaches, athletes and spectators alike. Sheard (2010, p. xi) noted that “mental toughness is one of the most ubiquitous terms used in sport”. Apart from an outstanding physical ability, mental toughness is thought to be the other important quality which is necessary to succeed in any sport. It is thought to be a crucial factor for elite athletes, since differences in physical and technical abilities are minimal at the professional level (Sheard, 2010). When talking to players and coaches, researchers are frequently confronted with requests for procedures to develop mental toughness (Clough, Earle, & Sewell, 2002). In order to accommodate these requests, a clear definition and an operationalisation of the concept of mental toughness is needed first. In this chapter an overview on the most popular definitions of mental toughness is given.

Defining Mental Toughness

Early attempts to define mental toughness branched out into two directions. Some researchers proposed that it was a personality trait (Cattell, 1957; as cited in Sheard, 2010; Kroll, 1967, as cited in Sheard, 2010), whereas others viewed it as a state of mind (George, 1998; as cited in Sheard, 2010). Today, the attributes which are most often reported to represent mental toughness, include an unshakeable self-belief, effective coping when under pressure, resiliency, thriving on pressure, commitment, and the ability to remain fully focused (Connaughton, Wadey, Hanton, & Jones, 2008; Crust, 2008; Sheard, 2010). The main challenge when defining mental toughness is that nearly every positive psychological characteristic which is related to sporting success has been included in the concept of mental toughness at one time or another (Jones, Hanton, & Connaughton, 2002).

Very early work by applied sport psychologists was not grounded in theoretical and scientific investigation. This recently led to researchers emphasizing the importance of measures which have a sound theoretical underpinning, and reflect the unique demands of sports (Crust, 2007). To better understand the concept of mental toughness, most researchers chose a qualitative

approach using for example interviews with athletes and coaches (Clough et al., 2002; Jones et al., 2002).

One popular definition came from Jones et al. (2002), who defined mental toughness as the ability to "generally cope better than your opponent with the many demands that sport places on a performer" and to "specifically be more consistent and better than your opponents in remaining determined, focused, confident, and in control under pressure" (Jones et al., 2002, p. 209).

Many mental toughness definitions are based on the concept of hardiness, which is an individual trait that acts as a buffer between stressors and a person's reaction to them (Kobasa, Maddi, & Kahn, 1982). One of these widely used concepts is the so called 4C's model of mental toughness (Clough et al., 2002). In this concept the four C's stand for:

- *Control:* a tendency to feel and act as if one is influential, especially in stressful situations; the ability to transform a threatening situation into something more acceptable
- *Commitment:* a tendency to involve oneself rather than experience alienation from a certain task
- *Challenge:* a tendency to believe that change rather than stability is normal in life, with changes being opportunities to grow instead of threats to security
- *Confidence:* a tendency to have confidence in ones abilities and the belief to succeed

Although not exhaustive, the definitions above provide a good representation of the recurring themes in mental toughness research and the consensus which has been agreed upon by most researchers. For a more detailed review, see Crust (2007).

Measuring mental toughness

To date, most mental toughness assessments have been questionnaires (Crust, 2007). This study focused on three different mental toughness questionnaires, namely the MTQ48 (Clough et al., 2002), the SMTQ (Sheard, Golby, & van Wersch, 2009) and the TROSCI (Beattie, Hardy, Savage, Woodman,

& Callow, 2011). These questionnaires will be presented below. For an overview on other mental toughness measurements, see Sheard (2010).

Mental Toughness Questionnaire 48 (MTQ48)

This questionnaire was developed on the basis of the 4Cs model mentioned above (Clough et al., 2002). The core concept is developed from the notion of hardiness (Kobasa et al., 1982) which contains the factors control, commitment and challenge. Kobasa's concept was extended to further include a confidence factor. In this questionnaire Clough et al. (2002) split the subscales of control and confidence. The control scale was split into emotional and life control while the confidence scale was spilt into abilities and interpersonal confidence. Interviews with elite athletes, coaches and sports psychologists served as a basis for the development of this questionnaire (Clough et al., 2002).

Sports Mental Toughness Questionnaire (SMTQ)

The SMTQ is similar to the MTQ48 in conception and subscale names (Sheard et al., 2009). It was designed to meet the needs of athletes, and is based on raw data themes and quotes from qualitative studies. The SMTQ is comprised of a three-factor model with one higher-order general mental toughness factor. The three subscales are described as (Sheard et al., 2009):

- *Confidence:* The athlete's belief in his ability to achieve his goals and his belief that he is different from, and better than his opponent.
- *Constancy:* The athlete's determination to meet demands of training and competition, his willingness for setting goals, the possession of an unyielding attitude and an ability to concentrate.
- *Control:* The athlete's perception that he can bring about a desired outcome.

In a direct comparison of MTQ48 and SMTQ the expected correlations between global mental toughness scores and identically named subscales were found. Interestingly, the correlations between subscales which supposedly measured different things (e.g. MTQ48_Challenge and SMTQ_Confidence) were just as high (Crust & Swann, 2011). Validating these results is one of the core tasks of this study.

Trait Robustness of Self-Confidence Inventory (TROSCI)

The TROSCI is a recent questionnaire that was intended to assess athletes' robustness of self-confidence, which is an important characteristic of mentally tough athletes (Beattie et al., 2011). The authors define robust confidence beliefs as the ability to maintain those beliefs in the face of adversity. Moreover, it is assumed that robustness of self-confidence may contribute to performance more than the actual level of self-confidence (Beattie et al., 2011). The present study addresses these assumptions by including the Rosenberg Self-Esteem Scale (RSES) (von Collani & Herzberg, 2003), which measures the level of self-esteem.

Mental Toughness in Sports

Mental toughness has been examined with focus on one sport per study. These studies were done on swimming (Sheard & Golby, 2006), football (Crust, Nesti, & Littlewood, 2010) and martial arts. However, most sports-related studies of mental toughness used samples with athletes from various sports and achievement levels (Connaughton et al., 2008; Crust, 2009; Crust & Keegan, 2010; Nicholls, Polman, Levy, & Backhouse, 2008).

The studies vary greatly as to their field of interest and their findings. One study found a relationship between mental toughness and gender as well as age and experience. The results indicate that men and older or more experienced athletes are mentally tougher. No associations of mental toughness and level of achievement or type of sport were found though (Nicholls, Polman, Levy, & Backhouse, 2009). These findings are contrary to the results of Golby and Sheard (2004) who found that rugby players competing at the highest standard scored significantly higher in all three hardiness subscales than players from other levels. Another study reported significant relationship between mental toughness and isometric endurance (Crust & Clough, 2005).

High mental toughness in athletes has also been associated with a variety of personality characteristics like optimism and better coping strategies (Nicholls et al., 2008) or attitudes towards physical but not psychological risk-taking (Crust & Keegan, 2010). However, no relation could be found between mental toughness and affect intensity (Crust, 2009). In regard to sport injury rehabilitation, it was found that more mentally tough individuals display greater attendance at sessions, but athletes who scored lower on mental toughness showed more positive

behavior during clinic rehabilitation (Levy, Polman, Clough, Marchant, & Earle, 2006). Finally, regarding sporting success, wushu (a Chinese martial art) players who won medals at a Malaysian Championship were reported to have more self-confidence and better negative energy control than non-medalists (Kuan & Roy, 2007).

The development of mental toughness was studied in adolescent swimmers who had been exposed to psychological skill training. A rise in mental toughness scores and better performance after completing the training was found (Sheard & Golby, 2006). The results from another study on the development and maintenance of mental toughness indicate that developing mental toughness is a long-term process, encompassing a number of underlying mechanisms that work together. Once mental toughness is developed three mechanisms are perceived as particularly important to maintain it: an internalized desire to succeed, an adequate support network, and the effective use of psychological skills (Connaughton et al., 2008).

3.1.3 Martial Arts and Aggression

The relationship between practicing martial arts and aggression is a subject that elicits various opinions in public. They range from the position that martial arts training is responsible for athlete's aggression level to the view that martial arts can be used as an intervention for aggressive children. In the scientific community these assumptions are a field of avid discussion. Even though there is a considerable amount of research on socio-psychological outcomes of martial arts practice, no clear results have been established due to the many influential factors (Vertonghen & Theeboom, 2010).

Reynes and Lorant (2001) found that children beginning to practice judo or karate are not more aggressive than other children. This would contradict the so-called selection hypothesis which posits that aggressive children are more prone to select themselves into martial arts classes. They also found that after two years of training, these children still did not differ from a control group in overall aggression (Reynes & Lorant, 2004). Only the judoka in this sample showed higher anger scores and the results suggested that *Kata* (formal training without a partner) as well as meditation can be important for developing self-control in young

boys. In a different study, where only judoka were included, aggressiveness decreased with age and years of experience (Lamarre & Nosanchuk, 1999).

Another study, which focused on contact sports in general, reported that aggression was not related to practicing contact sports, but rather to body size (Lemieux, McKelvie, & Stout, 2002). The only study performed with regard to gender reported that females practicing high-level taekwondo and karate had higher anger scores than the general population (Wargo, Spirrison, Thorne, & Henley, 2007). As there is still not a definite answer whether judo practice leads to higher aggression scores in teenagers and young adults, this study will examine the correlation between judo and aggression, taking gender and experience into account.

3.1.4 2D:4D Digit Ratio

The abbreviation 2D:4D stands for the ratio of second to fourth digit (Manning, Scutt, Wilson, & Lewis-Jones, 1998). It is calculated by dividing the length of the second digit by the length of the fourth digit and it is a widely used putative marker of prenatal testosterone. Extensive research has been done over the past decade in the field of 2D:4D, totaling about 450 reports in 2011, with 1-2 journal papers per week currently being published (Voracek, 2011).

The 2D:4D ratio is set very early in development. One model proposes that *Hox* genes control the development of the digits and testes with high levels of fetal testosterone leading to a low 2D:4D ratio which in turn indicates high prenatal testicular activity (Manning et al., 1998).

The ratio seems to be rather stable throughout childhood and puberty (although mean 2D:4D shows a gentle rise with growth) and it is sexually dimorphic regardless of age and development (McIntyre, Ellison, Lieberman, Demerath, & Towne, 2005; Trivers, Manning, & Jacobson, 2006). Men tend to show lower values of 2D:4D than women do (Fink, Neave, & Manning, 2003; Manning et al., 1998). Digit ratio shows significant variation across ethnicities, but with the sexual dimorphism preserved within geographically distinct groups (Fink et al., 2006; Loehlin, McFadden, Medland, & Martin, 2006).

The measurement of 2D:4D can be achieved either directly with a Digital Vernier Caliper as described by (Manning, 2002a) or indirectly, by taking scans

and measuring the finger lengths on the computer or on paper prints. The majority of 2D:4D researchers use photocopies or scans (Voracek, Manning, & Dressler, 2007). It is still disputed whether differences between direct and indirect measurements exist, as some researchers have found differences (Manning, Fink, Neave, & Caswell, 2005) whilst others have not (Voracek & Dressler, 2006; Voracek & Offenmüller, 2007).

As for the question whether 2D:4D is heritable, one study shows that at least 66% of the variance in digit ratio is due to genetic factors (Paul, Kato, Cherkas, Andrew, & Spector, 2006, p. 218). Another study carried out on twins found a heritability of about 60-80% for their sample (Voracek & Dressler, 2007, p. 121). Furthermore, Voracek and Dressler (2009) reported that right-hand 2D:4D is more affected by biological factors, while left-hand 2D:4D is better explained by environmental influences.

Since testosterone-associated, sex-dependent abilities like spatial ability, speed, endurance, and strength are related to success in male-to-male physical competition, the relationship of these abilities with 2D:4D was investigated using sports as a proxy (Manning & Taylor, 2001). The results suggest that a low digit ratio is associated with a high level of achievement across a number of sports. Many other studies have found a significant negative association between 2D:4D and performance in sports. These studies include running speed for middle- and long-distance runners, football (Manning et al., 2003; Tester & Campbell, 2007), rugby, basketball (Tester & Campbell, 2007), skiing (Manning, 2002b) and fencing (Voracek, Reimer, Ertl, & Dressler, 2006).

A meta-analysis on 2D:4D and athletic prowess revealed that overall measures of athletic prowess are negatively linked to 2D:4D in both hands regardless of age or sex, and that neither the left nor the right hand systematically out-predicts the other in the domain of athletic prowess (Hönekopp & Schuster, 2010). These findings implicate that researchers should always study 2D:4D in both hands.

The physical abilities required for sporting success vary largely depending on the athletic discipline in question. Even though there is a relationship of 2D:4D in both endurance and strength related sports, is seems that 2D:4D predicts more variance in performance for the former than the latter (Manning, Morris, & Caswell,

2007; Tamiya, Lee, & Ohtake, 2012). These findings are supported by a study which found a rather weak but significant relationship between hand-grip strength and right hand 2D:4D, but not left hand 2D:4D in Indian and German men (Fink et al., 2006).

3.1.5 Hand-Grip Strength

A number of daily activities require some degree of hand-grip strength, and compared to other measures of physical health and muscle function it is rather easy to obtain (Gallup et al., 2007). Further, HGS is highly heritable and a sexually dimorphic indicator of blood testosterone levels, fat-free body mass and nutritional status (Gallup, O'Brien, White, & Wilson, 2010; Norman, Stobaus, Gonzalez, Schulzke, & Pirlich, 2011). Moreover, men with low testosterone levels tend to show lower HGS measures (Soyupek, Soyupek, Perk, & Ozorak, 2008).

In general, men have greater HGS than women and this finding remains constant throughout life. Right-handers seem to have about 10% more strength in the right hand than in the left, regardless of gender, while left-handers tend to have equal strength in both hands (Petersen et al., 1989; as cited in Gallup et al., 2007, p.424).

With regards to personality, HGS is significantly related to socially dominant behavior in older adolescent males. Perceived aggressiveness and social dominance can even be used to predict a male's HGS whereas no correlations could be found for females (Gallup et al., 2010). Another study found that male HGS predicted certain aspects of body morphology, past aggressive behavior and sexual behavior (i.e., high HGS males tend to have broader shoulders, are more aggressive, and have sex at an earlier age; Gallup et al., 2007). The female participants in this study showed no relationship between HGS and any of those measures.

Even though HGS and 2D:4D digit ratio seems to be related to testosterone, very few findings have been reported so far. Fink et al. (2006) found a relationship between 2D:4D and HGS of the right hand in German and Mizos men, regardless of age, height or weight. These findings could not be replicated in women (van Anders, 2007). As for judo, hand grip is a very prominent feature and has to be maintained throughout most of the competition. Due to this, it is

supposed that maximum grip strength is not significantly related to success, but rather endurance plays the more important role (Franchini, Del Vecchio et al., 2011; Franchini, Miarka et al., 2011; Franchini et al., 2005).

3.2 Hypotheses

In the following section, the various hypotheses related to mental toughness, 2D:4D digit ratio, hand-grip strength, and sporting success in judo are discussed. The primary goal of this study was to examine the factor structure of three relatively new mental toughness questionnaires (MTQ48, SMTQ, TROSCI). Furthermore, it was aimed to gather a more complete knowledge about the concept of mental toughness and its associations with other personality traits like self-esteem or aggression. Apart from psychological aspects, there was a focus on the physical measures of 2D:4D digit ratio and hand-grip strength. Additionally an attempt was made to predict sporting success in judo based on the variables which were gathered in this study, with a particular interest in the effect of mental toughness and 2D:4D.

Hypotheses related to Mental Toughness

Mental toughness was measured with three questionnaires: the MTQ48 (Clough et al., 2002), the SMTQ (Sheard et al., 2009) and the TROSCI (Beattie et al., 2011). In order to get information about their factor structure, all of them were analyzed with exploratory factor analysis and confirmatory factor analysis. Following Crust and Swann (2011) the MTQ48 and the SMTQ were compared with special focus on the questionnaires' identically named subscales. Also, the constancy subscale of the SMTQ was expected to be most similar to the commitment scale from the MTQ48. Since both questionnaires are supposed to measure mental toughness, strong correlations between their total scores as well as their subscales are expected (H_1). MTQ48 and SMTQ total scores should also be strongly correlated to the TROSCI total score and all three mental toughness questionnaires are expected to show modest correlations with RSES since self confidence is just one aspect of mental toughness (Clough et al., 2002; Sheard et al., 2009) (H_2). So far, there are not many findings on the association between mental toughness and sporting experience. Nevertheless, some studies already showed a positive correlation between these variables (Nicholls et al., 2009); hence, a positive relation is also assumed in this study (H_3).

Hypotheses related to Aggression

Since this study was conducted exclusively with judo athletes, personality traits which are particularly relevant to martial arts were also in the interest of this research and therefore measured. Self-reported aggression was assessed with the BPAQ (Herzberg, 2003) and correlations to mental toughness and self-esteem were expected to be small or nonexistent (H_4). Lamarre and Nosanchuk (1999) found that aggression in judoka went down with the number of years practicing judo, even when age was controlled for. Thus, a negative relation between BPAQ total score and judo experience is expected (H_5).

Hypotheses related to 2D:4D

Although a growing number of studies investigated the association between the 2D:4D digit ratio and sporting success during the past years (Manning et al., 2003; Tester & Campbell, 2007; Voracek et al., 2010), information for martial arts is still scarce. In line with these studies, the significance of 2D:4D differences within the sample across gender was checked for, expecting a lower ratio for men than for women (H_6). Also, male and female judoka were expected to show lower ratios than the general Austrian population (H_7). There have been findings of a positive relation between 2D:4D and BMI (Fink et al., 2003) which were not replicated though (Voracek et al., 2006). Therefore, this study will also look into possible correlations between 2D:4D and BMI (H_8).

On the possible relationship between 2D:4D and aggression, one study found no correlations for females, but men with lower digit ratio reported higher physical aggression scores (Bailey & Hurd, 2005) in the Buss-Perry-Aggression-Questionnaire (Buss & Perry, 1992). Austin, Manning, McInroy and Mathews (2002) also found no association between digit ratio and aggression regardless of gender. However, higher reactive aggression scores with low 2D:4D were reported for females (Benderlioglu & Nelson, 2004) and low directional asymmetry in digit ratio was found to predict indirect, but not direct aggression in women (Coyne, Manning, Ringer, & Bailey, 2007). In a meta-analysis, no evidence for a relationship between digit ratio and aggression was found for women, and regarding men, the correlations were negative, but small (Hönekopp & Watson, 2011). This study will examine a possible relationship between 2D:4D and self-reported aggression with regard to gender effects (H_9).

Hypotheses related to hand-grip strength

Hand-grip strength is seen as a measure for general muscle power and other traits like aggression (Gallup et al., 2007). This study expects to find that men have significantly higher results than women (H_{10}). Signs of fatigue in the form of differences between the first and second measurement were also examined (H_{11}). A relationship between right 2D:4D and grip strength in men could be found (Fink et al., 2006), but to date researchers have not confirmed this relationship in women (van Anders, 2007).

Since hand-grip strength as well as 2D:4D digit ratio seem to be markers of prenatal testosterone, a negative relationship with athletes showing either low 2D:4D and great hand-grip strength or vice versa is expected for the male athletes in this sample but not the females (H_{12}). This study also expects to find positive correlations between training intensity and hand-grip strength, since hand-grip strength is an indicator for muscle power (H_{13}). Although in previous studies aggression measures other than the BPAQ were used (Gallup et al., 2007), it is also checked for a positive relation between hand-grip strength and the total score of the BPAQ (H_{14}).

Hypotheses related to sporting success

Golby and Sheard (2004) found a relation between the level at which rugby players competed and their mental toughness. Following these results a positive correlation between success in judo and scores on mental toughness questionnaires are expected (H_{15}). As already mentioned above, there is extensive literature (Manning et al., 2003; Tester & Campbell, 2007; Voracek et al., 2010) on 2D:4D and sporting success. In agreement with this research, a negative correlation is expected (H_{16}). Furthermore, isometric hand-grip strength as opposed to hand-grip endurance does not seem to be a good predictor for success in judo (Franchini, Miarka et al., 2011; Franchini et al., 2005; Sanchez et al., 2011). Only one study found a relationship between both parameters for the female participants of their study (Sanchez et al., 2011). Hence no association between these two variables was expected in the current study (H_{17}).

Potential indicators of success in judo (for a comparison to other sports, see Tester & Campbell, 2007; Voracek et al., 2010), such as BMI, experience, training intensity, mental toughness, and 2D:4D are included in a dominance analysis

model, in order to see whether significant effects of these predictors are obtained (H_{18}).

4 Methods

This section gives information on the measurement tools which were used in the study. The study's primary goal was to explore the relationship between mental toughness and sporting success in judo athletes. To get a broad picture of the concept of mental toughness, different questionnaires were used (MTQ48, SMTQ, TROSCI). Subsequently, the different instruments were compared to each other in order to check their quality, similarities, and differences. Further, the influence of variables like BMI, training intensity and experience, as well as that of physical measures (HGS, 2D:4D), and other personal characteristics (self-esteem, aggression) was examined on success in judo.

4.1 Sample

An ethnically homogeneous sample (95% native Austrians) consisting of 140 active judoka was collected. Out of these 140 athletes 94 (67%) were men and 46 (33%) were women. This slightly skewed gender distribution was expected, since judo is a sport which is largely dominated by men. Thus, this sample represents the average sex ratio in the general Austrian judo population. The judoka were predominantly teenagers and young adults from clubs all over Austria. The lower and upper quartiles of the age distribution (i.e., the 25th and the 75th percentiles) were 15 and 20 years and the participants' age ranged from 12 to 50 years (*M* = 18.5, *SD* = 6.6). Self-reported training times were up to 25 hours per week (*M* = 7, *SD* = 4.5 hours) and judo experience ranged from 2 months to 27 years (*M* = 10, *SD* = 4.7 years).

Sample breakdown by belt color showed a high overall skill level with 50 (35.7%) athletes wearing a black, 45 (32.1%) wearing a brown, and 20 (14.3%) wearing a blue belt. Accordingly, 120 (85.6%) participants ranged in the three highest categories ("I have competed at national level", "I think I could represent my country", "I have represented my country") on a 10-point measure of sport performance (see chapter 4.3).

Average height for men was 174 cm (*SD* = 8.3) and average weight was 69.2 kg (*SD* = 15.6). These measures resulted in a mean body mass index (BMI) of 22.6 (*SD* = 3.6). The female participants reported an average height of 165 cm (*SD* = 5.5) and an average weight of 57.4 kg (*SD* = 8.1) resulting in a mean BMI of 21 (*SD* = 2.3). Out of 140 Judoka, 14 (10%) were left-handed.

Participants volunteered to take part in this research; they were not paid or provided with any incentives.

4.2 Procedure

Data were collected during two rounds of the second-highest judo club championship league in Austria (Place: Wiener Neudorf, Austria; Dates: May 28th and June 10th 2011) and also during a national six-day training camp in Rauris, Austria (July 10th to 15th 2011). Athletes and their coaches were approached on-site, and upon agreement to volunteer they were led to a quiet room within the facilities where they completed a seven-page form comprised of a personal information sheet and the personality measures (see chapter 4.3). Afterwards, digital scans of the participants' palms were taken. Hand-grip strength was measured with a hand-grip dynamometer (see chapter 4.3), and two measurements per hand per person were recorded. Regarding the goal of this study, participants were given some basic information about the study's focus on the relationship between personality and sporting success, but they were unaware of the background and the central hypotheses.

For the duration of the questionnaire, the investigator was available for answering questions from participants. It took the athletes an average of about 30 minutes to complete the form and the physical measurements. Study participation was on an informed-consent basis and was under conditions of privacy and confidentiality. After completing the data collection athletes were debriefed and thanked.

4.3 Instruments

HGS Dynamometer

Hand-grip strength was measured with a hand-grip dynamometer (Bremshey EH101). The participants were told to stand upright hold the arm straight down at their side and squeeze the dynamometer as hard as possible. All athletes had to complete four valid measurements (i.e., two per hand, alternating). HGS was noted in kg.

Finger-length measures

The palmar-view scans were taken with a flatbed-scanner (HP Scanjet 4370 Photo Scanner). Athletes had to take jewelry off their hands before doing the scans and persons with hand injuries were omitted from the study. During the scan the fingers 2-5 had to be held straight and touching each other, the thumb was splayed out to the side. To improve image quality, aluminum foil was used to minimize the incidence of light.

All scans were immediately checked for blurring and repeated if necessary. Files were named corresponding with the participants' code on the questionnaire. Lengths of the second and fourth finger were independently measured twice by trained investigators (Katharina Heiny, Hannah Kaseder) with the Autometric Program Version 2.2 (2004). All measurements were made blind to the other data collected for this study and the investigators were blind to each others' measurements. Measures were made from the central point of the tip of the second finger to the central point of the basal crease of the second finger and divided by the same measure from the fourth finger to calculate digit ratio. Values lower than 1 indicate that the ring finger is longer than the index finger.

Personal Information Sheet

The first page of the form comprised an identification code to guarantee anonymity, as well as some personal information (sex, age, height, weight, years of judo experience, weight class, training intensity, belt color, nationality, number of severe judo related injuries, handedness) and a German version of the 10-point measure of sport performance (as previously used by Manning & Taylor, 2001)

Mental Toughness Questionnaire 48 (MTQ48)

The MTQ48 (Clough et al., 2002) is a 48-item inventory to measure mental toughness. It is comprised of four subscales (Challenge, Control, Commitment and Confidence) and items are rated on a 5-point Likert scale ranging from “strongly disagree” to “strongly agree”. The MTQ48 provides an overall score for mental toughness as well as a profile of the four subscale scores. According to Clough et al. (2002) the MTQ48 appears to be an accurate (overall Cronbach’s alpha .90), fair, and useful way of evaluating mental toughness. The proposed factor structure has been recently confirmed (Horsburgh, Schermer, Veselka, & Vernon, 2009).

Sports Mental Toughness Questionnaire (SMTQ)

With this 14-item questionnaire, Sheard et al. (2009) tried to create a mental toughness questionnaire that specifically fits the needs of athletes. It is based on a three-factor model with one higher-order factor. Responses to the items are made on a four-point Likert scale anchored by “not at all true” and “very true”. The SMTQ provides an overall mental toughness score as well as scores for the three subscales – Confidence, Constancy and Control. Sheard et al. (2009) found satisfactory reliability and divergent validity, as well as adequate model fit and discriminative power.

Trait Robustness of Self-Confidence Inventory (TROSCI)

The TROSCI is a recently-developed questionnaire which is comprised of twelve Items (Beattie et al., 2011). Athletes were asked to rate the extent to that they agreed to or disagreed with each statement on a 9-point Likert scale ranging from “strongly disagree” to “strongly agree”. At the beginning of the inventory standard, anti-social-desirability instructions were included, encouraging participants to respond honestly. The questionnaire was specifically designed for use in competitive settings. Although Beattie et al. (2011) made it an eight-item final version excluding four items due to high standardized residuals, the original version was used in this study to confirm or falsify their findings.

Rosenberg Self Esteem Scale (RSES)

The revised German form of Rosenberg’s Self Esteem Scale (von Collani & Herzberg, 2003) was used in this study. It is one-dimensional and consists of ten items. These are scored using a four-point Likert scale with responses ranging

from “strongly disagree” to “strongly agree”. The authors (von Collani & Herzberg, 2003) found stable internal consistency measures across two different samples. Cronbach’s α was high with .84 and .85 respectively.

Buss-Perry Aggression Questionnaire (BPAQ)

The German form (Herzberg, 2003) of the most widely used self-report measure of aggression (Buss-Perry Aggression Questionnaire, BPAQ; Buss & Perry, 1992) was administered. It assesses an overall aggression score as well as the four subscales physical aggression, verbal aggression, anger and hostility on five-point Likert scales ranging from “extremely uncharacteristic of me” to “extremely characteristic of me”. Satisfying psychometric requirements in the German form were achieved by excluding two items from the original version, reducing the questionnaire to 27 items altogether (Herzberg, 2003).

4.4 Data analysis

All calculations and data analysis were executed with SPSS 17.0 for Windows and its add-on program AMOS 20. The dominance analysis was completed with an EXCEL file provided by James LeBreton (available online at http://www1.psych.purdue.edu/~jlebreto/downloads.html [03.02.2012]).

Measurement repeatability for the 2D:4D measurements were assessed with single-score intraclass correlation coefficients (ICC; two-way mixed-effects model with absolute-agreement definition; Voracek et al., 2007). The *ICC*s (depicted in Table 1) for the individual finger lengths scoring above .98 with all *p*s <.001 indicate a strong agreement. The directional asymmetry in digit ratios was calculated as D_{R-L} = R2D4D – L2D4D and the two independent measurements were averaged for further data analysis.

Table 1 ICCs for digit ratio (*N* = 140)

	ICC	*F*	*p*
L 2D	.990	229.481	< .001
L 4D	.995	407.153	< .001
R 2D	.988	205.631	< .001
R 4D	.991	234.363	< .001
L 2D:4D	.962	52.217	< .001
R 2D: 4D	.941	39.543	< .001
D_{R-L}	.812	10.146	< .001

*df*1 = 139, *df*2 = 139

Belt color and the self-reported rating in the sports performance questionnaire (see Instruments) were taken as measures for judo performance. A factor score was calculated for every athlete. Hand-grip strength was averaged for data analysis except stated otherwise. For the questionnaires (MTQ48, SMTQ, TROSCI, RSES, BPAQ) total scores and subscale scores were calculated. BMI was calculated as weight divided by height squared (kg/m²). Significance was set to $p < .05$ (two-tailed).

5 Results

The results presented in this chapter show the outcomes of this study with regard to the different hypotheses. One of the major goals of this study was to investigate several hypotheses which are related to testosterone and its effect on men and women. Several differences between the sexes were expected, hence it is crucial to outline possible differences on the most important variables. Table 2 shows the descriptive statistics for the athletes' personal information variables, along with tests for sex differences.

Table 2 Sex differences in study participants (*N* = 140)

Variable	Mean (*SD*) Females	Mean (*SD*) Males	*df*	*t*	*p*	*d*	*U*-Test
Age (years) +	16.6 (3.52)	19.4 (7.58)	137.73	-2.944	.004**	-0.53	.160
Height (cm)	165 (5.54)	174 (8.31)	125.26	-7.695	<.001***	-1.39	
Weight (kg) +	57.4 (8.11)	69.2 (15.60)	137.44	-5.870	<.001***	-1.06	<.001***
BMI	21.0 (2.32)	22.6 (3.56)	126.97	-3.077	.003**	-0.55	
Experience (years) +	9.9 (4.05)	10.2 (5.01)	138	-0.337	.736	-0.06	.976
Training intensity (hours/week) +	7.1 (3.93)	7.1 (4.81)	138	-0.050	.960	-0.01	.545

df, degrees of freedom; *t, t*-Test for independent groups with *p*-Values; *d*, Cohen's *d* effect size; *U*-Test, *p*-Value of the Wilcoxon-Mann-Whitney-Test, + normality cannot be assumed

***$p < .001$, **$p < .01$, *$p < .05$

The data show that the male and female judoka were of comparable age. Self-reported training intensity and years of experience did not differ between the sexes, and normative sex effects in height, weight, and BMI emerged in the sample. Since *t*-Tests assume normality of the variable in the sample, the *U*-Test was applied for some variable which did not meet this assumption. Effect sizes in this study were calculated with the formula $d = t * \sqrt{\frac{n_A+n_B}{n_A*n_B}}$ where effects are

interpreted as small around 0.2, medium around 0.5 and large above 0.8 (Bortz & Döring, 2006, p. 607).

To check the internal consistency of the questionnaires, Cronbach's α was calculated: The results can be viewed in Table 3. The overall internal consistency of all questionnaires (MTQ48, SMTQ, TROSCI, RSES, BPAQ) was found to be satisfactory ranging from .788 to .886. However some subscales were found to have problems with internal consistency ($\alpha < .70$). As seen in Table 3, the MTQ48 subscales of challenge and control and the SMTQ subscales of constancy and control had inadequate internal consistency having a Cronbach's α between .396 and .609. Moreover, two items of the MTQ48 control subscale (Item 26, Item 34) feature negative discriminatory power.

Table 3 Internal consistency of the questionnaires and subscales

Questionnaire/Subscale	Number of Items	*N*	Cronbach's α
MTQ	48	119	**.856**
MTQ_Challenge	8	135	.520
MTQ_Commitment	11	131	.725
MTQ_Control	14	128	.396
MTQ_Confidence	15	136	.774
SMTQ	14	129	**.788**
SMTQ_Confidence	6	135	.727
SMTQ_Constancy	4	135	.550
SMTQ_Control	4	136	.609
TROSCI	12	129	**.854**
RSES	10	135	**.849**
BPAQ	27	123	**.886**
BPAQ_Physical Aggression	8	133	.837
BPAQ_Verbal Aggression	5	134	.682
BPAQ_Anger	6	138	.741
BPAQ_Hostility	8	134	.729

5.1 Hypotheses related to Mental Toughness

Before testing any hypotheses related to mental toughness, an exploratory and a confirmatory factor analysis were conducted on the three mental toughness questionnaires (MTQ48, SMTQ, TROSCI). Since the KMO measures for the questionnaires were acceptable (.690 for the MTQ48, .768 for the SMTQ and .872 for the TROSCI), an exploratory factor analysis could be performed. Factors with an eigenvalue greater than 1 were extracted (Kaiser's criterion) and a screeplot was made for an additional graphic check.

5.1.1 Exploratory Factor Analysis of the MTQ48, SMTQ and TROSCI

For the MTQ48, Kaiser's criterion suggested the extraction of 16 factors explaining 70.6% of the total variance. In the screeplot (Figure 2) an inflexion can be seen at the fourth factor, so three factors were extracted explaining 30.9% of the total variance. Principal component analysis with varimax rotation was used and the rotated component matrix can be viewed in Table 4. Only factor loadings with values greater than .40 were included in the component matrices.

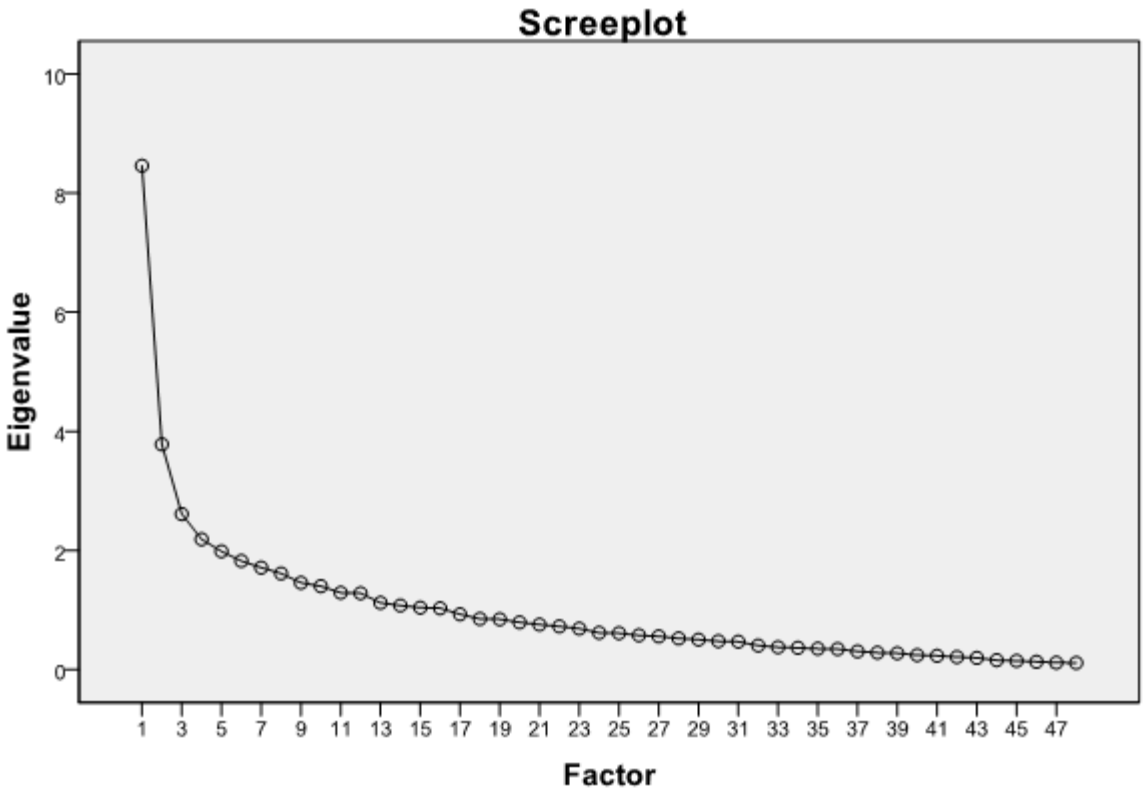

Figure 2 Screeplot of exploratory factor analysis for MTQ48

Table 4 Rotated Component Matrix for the MTQ48

Rotated Component Matrix

	Component		
	1	2	3
mtq1	.534		
mtq2	.503		
mtq3	.416	.455	
mtq4	.473		
mtq5	.653		
mtq6		.485	
mtq7	.490		
mtq8			
mtq9			.576
mtq10			.556
mtq11			.530
mtq12			
mtq13		.425	
mtq14			.475
mtq15		.441	
mtq16		.525	
mtq17	.646		
mtq18			
mtq19	.553		
mtq20	.652		
mtq21		.512	
mtq22			.534
mtq23			
mtq24		.507	

Rotated Component Matrix

	Component		
	1	2	3
mtq25	.453		
mtq26			
mtq27			.531
mtq28			
mtq29			
mtq30			
mtq31		.481	
mtq32		.402	
mtq33			
mtq34			-.461
mtq35			.532
mtq36		.559	
mtq37			.582
mtq38	.615		
mtq39	.575		
mtq40			
mtq41	.450		
mtq42			.545
mtq43	.590		
mtq44	.533		
mtq45			
mtq46	.440		
mtq47			
mtq48	.557		

The same procedure was used for the SMTQ. Kaiser's criterion suggested the extraction of four factors explaining 58.4% of the total variance. This number of factors is corresponding to the inflexion in the screeplot (Figure 3) at factor five. The rotated component matrix is presented in Table 5.

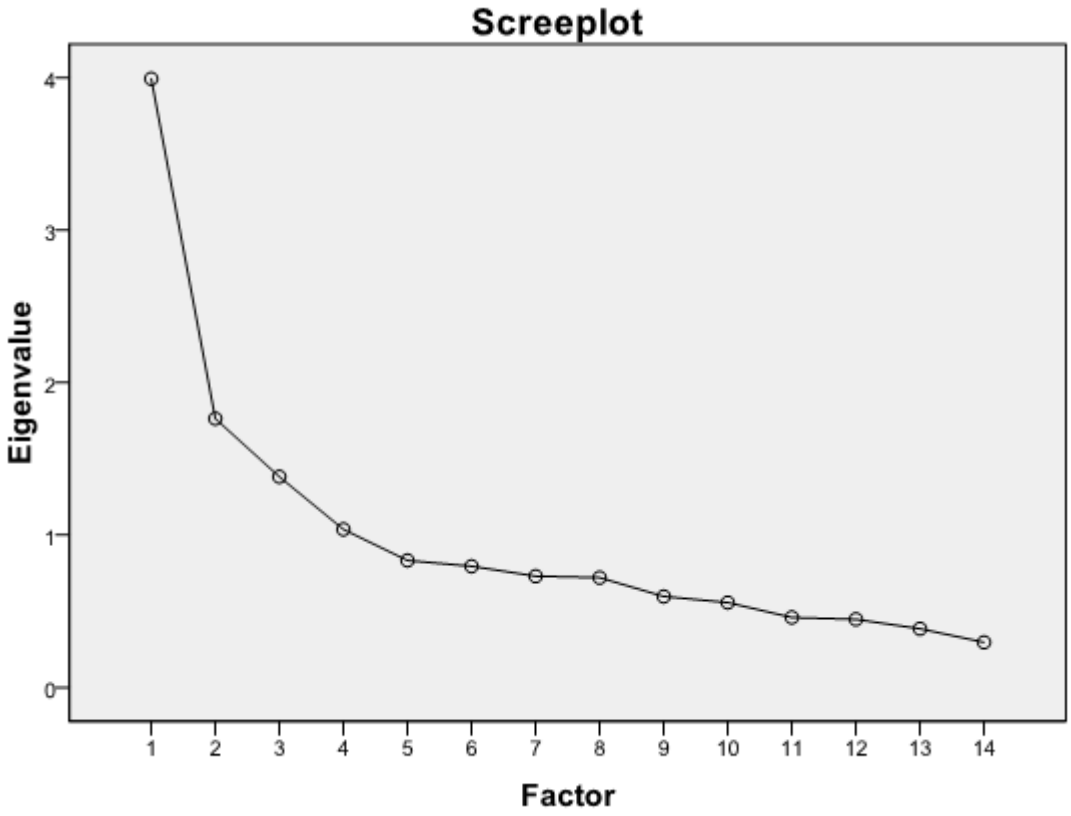

Figure 3 Screeplot of exploratory factor analysis for SMTQ

Table 5 Rotated Component Matrix for the SMTQ

Rotated Component Matrix

	Component			
	1	2	3	4
smtq1				.775
smtq2		-.468		
smtq3	.493	.590		
smtq4	.678			
smtq5	.770			
smtq6	.660			
smtq7			.742	
smtq8	.672			
smtq9			.687	
smtq10			.678	
smtq11		.622		
smtq12		.732		
smtq13				.690
smtq14	.577			

For the TROSCI, the extraction of three factors was suggested following Kaiser's criterion. These factors would explain 62.0% of the total variance. However, the inflexion in the screeplot (Figure 4) is at the second factor, so a one-factor structure was assumed explaining 42.8% of the total variance. Due to the one-factor solution, no rotation was needed and Table 6 lists the component matrix for the TROSCI.

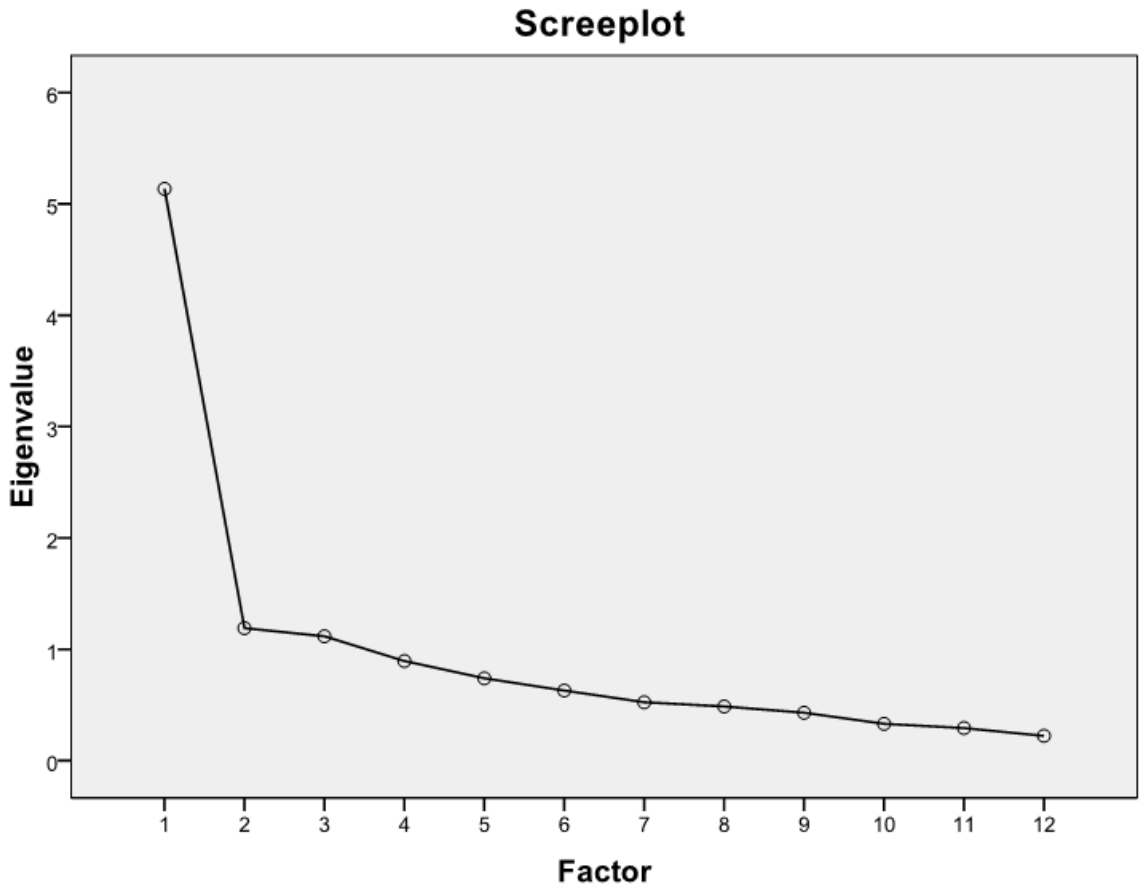

Figure 4 Screeplot of exploratory factor analysis for TROSCI

Table 6 Component Matrix for the TROSCI

Component Matrix	
	Component
	1
trosci1	.692
trosci2	.675
trosci3	
trosci4	.600
trosci5	.708
trosci6	.762

Component Matrix	
	Component
	1
trosci7	.695
trosci8	.800
trosci9	.743
trosci10	.596
trosci11	
trosci12	.803

5.1.2 Confirmatory Factor Analysis of the MTQ48, SMTQ and TROSCI

In addition to exploratory factor analysis, confirmatory factor analysis was conducted. First, the models proposed by the authors were checked and then the alternative models for SMTQ and MTQ48 were created which had been suggested by exploratory factor analysis. This method is used to examine the fit between the theoretical model and the collected data. The originally proposed models can be viewed in Figure 4 for the MTQ48 (Clough et al., 2002), Figure 5 for the SMTQ (Sheard et al., 2009) and Figure 6 for the TROSCI (Beattie et al., 2011).

As alternative models, a 3-factor solution for the MTQ48 (“MTQ48 3F”) and a 4-factor solution for the SMTQ (“SMTQ 4F”) were suggested by the results of exploratory factor analysis. Before conducting the analysis, data were checked for normality and outliers. The model fit for the original MTQ structure could not be computed, as the covariance matrix was not positive definite. The results for the model fit of the other questionnaires can be viewed in Table 7.

Values of the CFI and the NFI were <.95 for all tested models, which indicates a poor model fit. Overall, the TROSCI seems to do best with both values above .80. Also, the RMSEA values should be <.05, but none of the questionnaires met this. Compared to the other questionnaires, the alternative 3-factor structure of the MTQ 48 seems to provide the best fit with .074. As all *p*-values for the χ^2-statistics were significant, the models should be rejected. Between the original version of the SMTQ and the alternative 4-factor model, the latter one displays slightly better model fit for all fit indices.

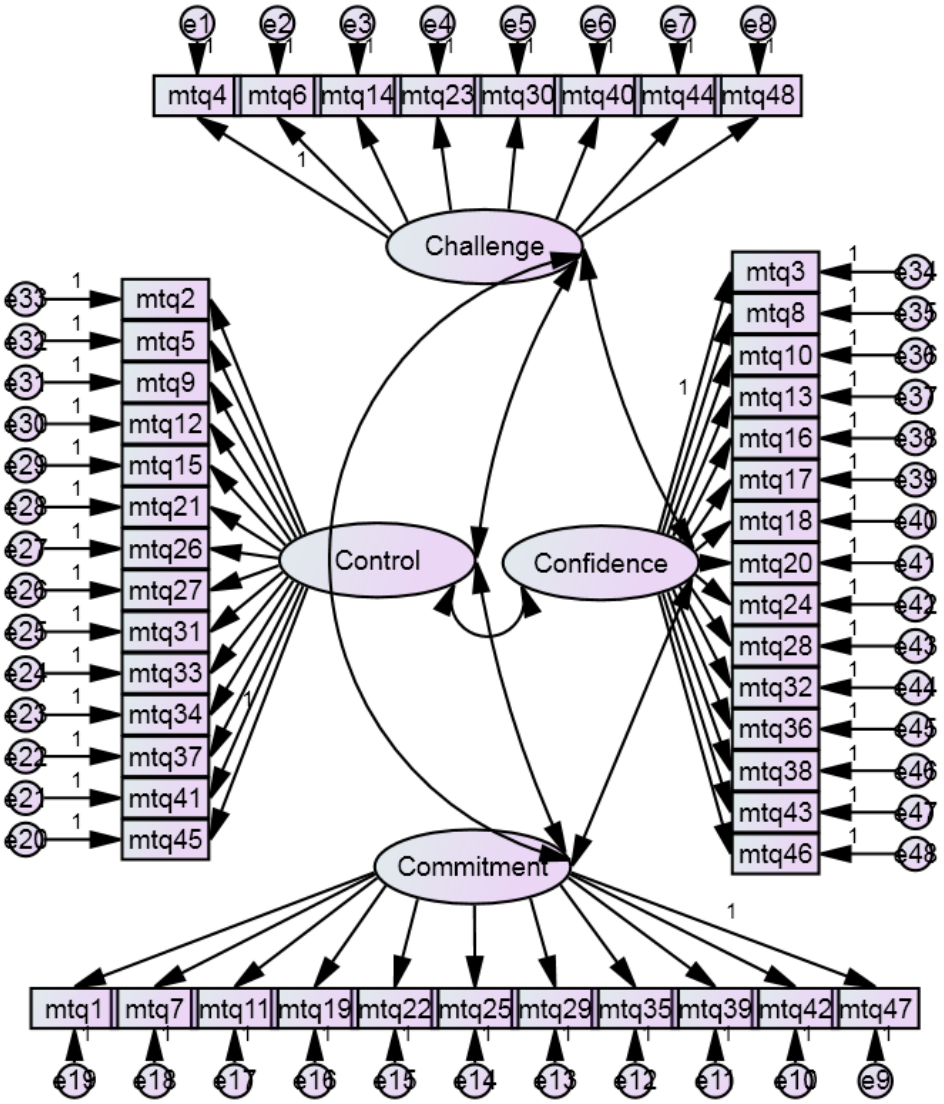

Figure 5 Factor structure MTQ48

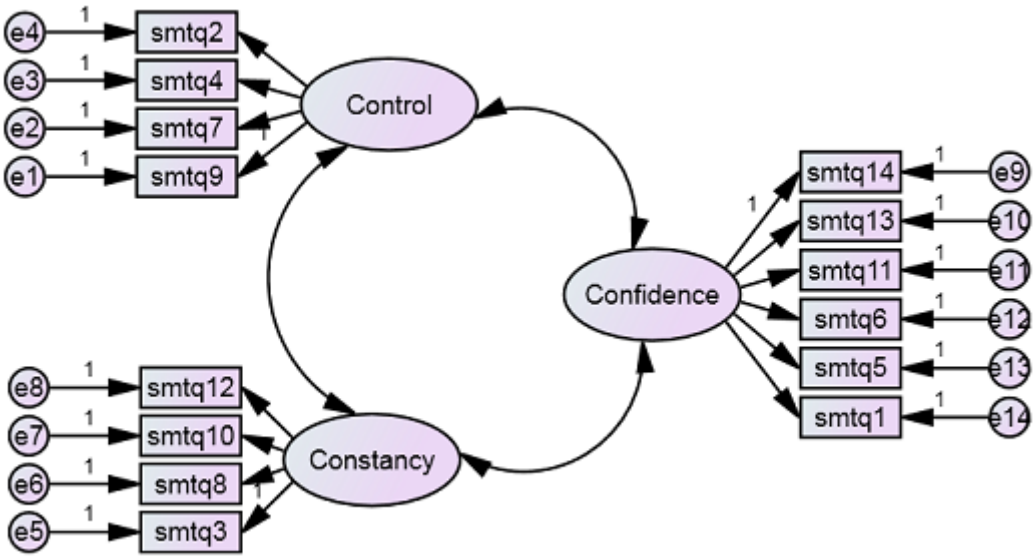

Figure 6 Factor structure SMTQ

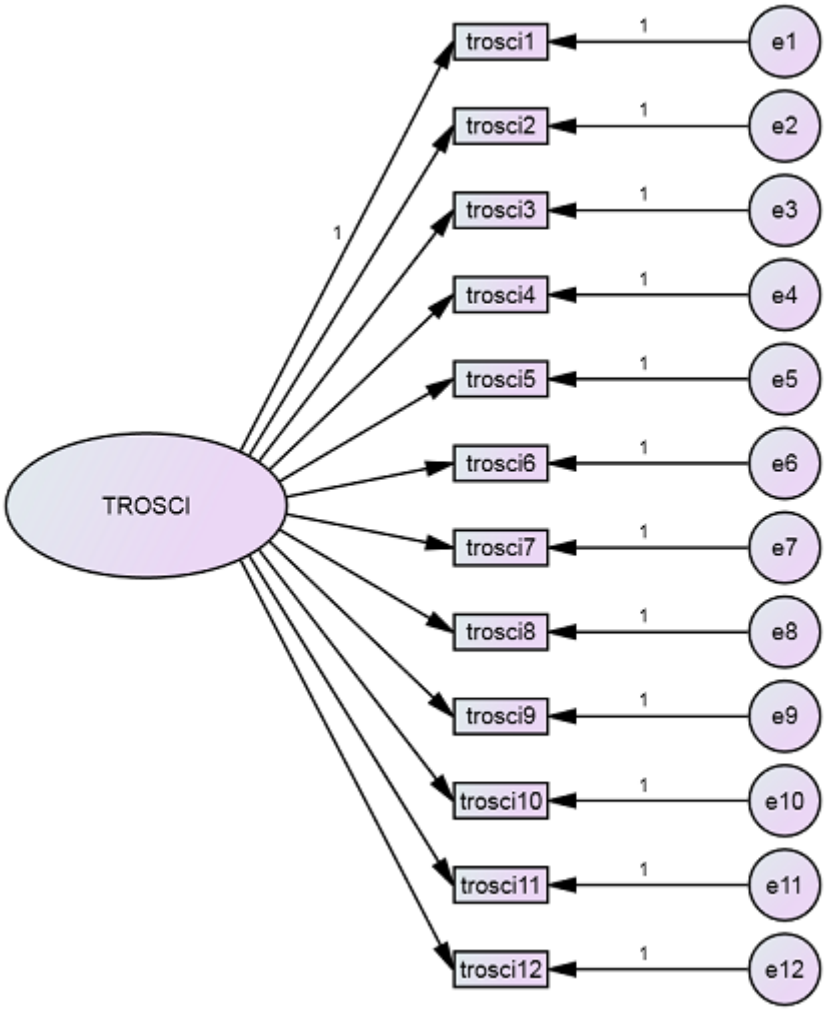

Figure 7 Factor structure TROSCI

Table 7 Model fit for mental toughness questionnaires

Model	χ^2	*p*	*CFI*	*NFI*	*RMSEA*
MTQ48 3F *N* = 119	1766.397	< .001	.553	.339	.074
SMTQ *N* = 129	153.711	< .001	.784	.666	.092
SMTQ 4F *N* = 129	136.093	< .001	.824	.704	.085
TROSCI *N* = 129	125,682	< .001	.875	.803	.102

CFI, Comparative Fit Index; *NFI*, Normed Fit Index; *RMSEA*, Root Mean Square Error of Approximation; χ^2-Statistic with *p*-Values

H_1: *The MTQ48 and the SMTQ are both supposed to measure mental toughness, therefore strong positive correlations between their total scores as well as their subscales were expected. Subscales with similar names were expected to be most closely related, and the constancy subscale of the SMTQ was expected to be most similar to the commitment scale from the MTQ48.*

Table 8 Pearson correlations between MTQ48 and SMTQ (*N* = 140)

Scale	MTQ total	MTQ Challenge	MTQ Commitment	MTQ Control	MTQ Confidence
SMTQ total	**.681****	.465**	.550**	.512**	.622**
SMTQ Confidence	.567**	.421**	.405**	.378**	**.573****
SMTQ Constancy	.548**	.383**	**.625****	.334**	.411**
SMTQ Control	.451**	.273*	.281*	**.460****	.410**

Subscales predicted to be most closely matched are highlighted in bold. ***p* < .001, **p* < .01

As shown in Table 8, MTQ48 and SMTQ total scores showed the strongest correlation being .681. The correlations of subscales which were predicted to be most closely matched (MTQ confidence – SMTQ confidence, MTQ control – SMTQ control, MTQ commitment – SMTQ constancy) were all found to be significant and stronger than the correlations between the other subscales.

H_2 & H_3: *MTQ48 and SMTQ total scores should be strongly correlated to the TROSCI total score and all three mental toughness questionnaires are expected to show moderate correlations with the RSES since self confidence is just one aspect of mental toughness. Another positive relationship is expected between mental toughness and judo experience.*

While MTQ48 and SMTQ showed a strong correlation of .681 (Table 8), the third mental toughness questionnaire (TROSCI) was found to correlate only moderately with the MTQ but stronger with the SMTQ. Interestingly, the RSES correlated significantly with all three mental toughness questionnaires. Correlations being just as high as between the mental toughness questionnaires. All correlations and significance levels are displayed in Table 9. Experience was also significantly positively related to MTQ and SMTQ scores, but the negative relationship with the TROSCI was not found to be significant.

Table 9 Pearson correlations between MTQ, SMTQ, TROSCI, RSES, and judo experience (*N* = 140)

Variables	TROSCI	RSES	Experience
MTQ48	.476***	.623***	.285**
SMTQ	.608***	.658***	.208*
TROSCI		.471***	-.049

***p < .001, **p < .01, *p < .05

5.2 Hypotheses related to Aggression

H_4 & H_5: *Correlations between aggression and mental toughness or self-esteem were expected to be small or nonexistent. Also, a negative relation between BPAQ total score and judo experience is expected.*

Table 10 shows all correlations of the BPAQ total score with mental toughness, self-esteem and experience were negative, although the correlation with the TROSCI did not reach statistical significance. Between the subscales of the BPAQ, physical aggression had the strongest negative relationship with judo experience and the RSES. Verbal aggression was unrelated to any of the other variables. The anger subscale was significantly and negatively related to all variables except for the TROSCI, where the relationship did not reach statistical significance. The hostility score showed the strongest correlations to all questionnaires with values between -.245 and -.486, but its relation to judo experience was not significant.

Table 10 Pearson correlations between aggression and MTQ, SMTQ, TROSCI, RSES, and judo experience (*N* = 140)

Variables	MTQ48	SMTQ	TROSCI	RSES	Experience
BPAQ Total	-.244**	-.274**	-.142	-.316***	-.248**
BPAQ Physical Aggression	-.113	-.145	-.047	-.169*	-.210*
BPAQ Verbal Aggression	-.029	-.026	.048	-.011	-.135
BPAQ Anger	-.171*	-.222**	-.162	-.249**	-.265**
BPAQ Hostility	-.396***	-.406***	-.245**	-.486***	-.151

***p < .001, **p < .01, *p < .05

5.3 Hypotheses related to 2D:4D

H_6 & H_7: *2D:4D differences within the sample across gender were checked, with the expectation of a lower ratio for men than women. Also, male and female judoka, were expected to show lower ratios than the general Austrian population.*

Sex differences between judo athletes were checked with an unpaired *t*-test. The results are presented in Table 11. The sex differences in digit ratio were significant and of moderate size for both hands. For directional asymmetry (D_{r-l}) no gender-related differences could be reported. To compare judo athletes to the Austrian norm population, 2D:4D values of 0.96 for men and 0.98 for women were used (Voracek et al., 2006, p. 438). As reported in Table 12, judo athletes had significantly lower digit ratios than the norm population regardless of hand and gender.

Table 11 digit ratio sex differences in judo athletes

2D:4D	Males (*N* = 94) Mean (*SD*)	Females (*N* = 46) Mean (*SD*)	*df*	*t*	*p*	*d*
Left hand	0.946 (0.034)	0.960 (0.033)	138	-2.199	.030*	-0.40
Right hand	0.942 (0.034)	0.960 (0.033)	138	-2.972	.003**	-0.53
D_{r-l}	-0.004 (0.023)	0.000 (0.022)	138	-1.067	.288	-0.19

df, degrees of freedom; *t, t*-test for independent samples with *p*-Values; *d*, Cohen's *d* effect size; ***p* < .01, **p* < .05

Table 12 Digit ratio differences between judo athletes and the Austrian norm population

sex	2D:4D	Mean (*SD*)	*df*	*t*	*p*
Male (*N* = 94)	left	0.946 (0.034)	93	-3.928	< .001***
	right	0.942 (0.034)	93	-5.063	< .001***
Female (*N* = 46)	left	0.960 (0.033)	45	-4.176	< .001***
	right	0.960 (0.033)	45	-4.102	< .001***

df, degrees of freedom; *t, t*-test one sample with *p*-Values; ***p* < .001, ***p* < .01, **p* < .05

H_8 & H_9: *This study looked into possible correlations between 2D:4D and BMI. Furthermore, a possible relationship between 2D:4D and self-reported aggression was examined with special attention to gender effects*.

Correlations of digit ratios with BMI and BPAQ overall and subscale scores are shown in Table 11. For BMI, the positive correlations presented directional consistency across gender and hands, but only left hand 2D:4D and BMI correlated significantly. The relationship between aggression and digit ratio for female participants was consistently positive for all subscales and total BPAQ score, but associations were small and did not reach statistical significance. For males, all correlations of 2D:4D and aggression were negative with exception of the anger and hostility subscales and none of which were significant.

Table 13 Correlations of aggression and BMI with digit ratio

sex	2D:4D	BMI	BPAQ total	BPAQ Physical Aggression	BPAQ Verbal Aggression	BPAQ Anger	BPAQ Hostility
Male (*N* = 94)	left	.255*	-.037	-.050	-.096	.006	.015
	right	.186	-.112	-.099	-.156	-.045	-.059
Female (*N* = 46)	left	.159	.159	.096	.113	.088	.213
	right	.076	.173	.131	.106	.162	.150

*$p < .05$

5.4 Hypotheses related to Hand-Grip Strength

H_{10} & H_{11}: *This study expects to find that men have higher grip strength than women. Signs of fatigue in the form of differences between the first and second measurement were also examined*.

Before performing *t*-tests, *ICC*s for the first and second measurement of hand-grip strength were conducted. The *ICC*s were .963 for left hand and .956 for the right hand, indicating a high agreement between the measurements. As can be seen in Table 14, men had significantly higher hand-grip strength than females did in both hands. Signs of fatigue were only found for women's left hands, where results from the second measurement were significantly lower than from the first one. These results are displayed in Table 15.

Table 14 sex differences for hand-grip strength

HGS	Males (*N* = 94) Mean (*SD*)	Females (*N* = 46) Mean (*SD*)	*df*	*t*	*p*	*d*
Left hand	44.2 (11.48)	30.3 (5.32)	137.716	9.762	< .001***	1.757
Right hand	46.3 (11.84)	31.5 (4.92)	135.353	10.447	< .001***	1.880

df, degrees of freedom; *t, t*-test for independent samples with *p*-Values; *d*, Cohen's *d* effect size; ****p* < .001 ***p* < .01, **p* < .05

Table 15 differences between HGS measurements

sex	HGS	1st measurement mean (*SD*)	2nd measurement mean (*SD*)	*df*	*t*	*p*
Male (*N* = 94)	left	44.2 (11.32)	44.1 (11.98)	93	0.138	.891
	right	46.4 (11.85)	46.3 (12.19)	93	0.114	.909
Female (*N* = 46)	left	31.0 (5.01)	29.6 (5.87)	45	3.806	< .001***
	right	31.5 (4.83)	31.5 (5.34)	45	-0.100	.921

df, degrees of freedom; *t*, paired *t*-test with *p*-Values; ****p* < .001, ***p* < .01, **p* < .05

H_{12}, H_{13} & H_{14}: *A negative relationship between HGS and 2D:4D was expected for the male athletes in this sample but not the females. It was also*

assumed that positive correlations between training intensity and hand-grip strength would be found. The relation between hand-grip strength and the total score of the BPAQ was also measured.

The results in Table 16 indicate that all associations between HGS and 2D:4D are positively correlated for males, but never reached statistical significance. For females, the results were directionally inconsistent and not significant. Training intensity was positively correlated with HGS across hands and gender, but the only significant association could be found for left hand HGS in males. Total BPAQ score showed a negative relationship with HGS for men and women, but it only reached significance for men.

Table 16 Correlations between HGS, 2D:4D, training and BPAQ

sex	HGS	Left 2D:4D	Right 2D:4D	Training intensity	BPAQ
Male (*N* = 94)	left	.083	.135	.212*	-.231*
	right	.083	.114	.105	-.293**
Female (*N* = 46)	left	.013	-.069	.066	-.136
	right	-.080	-.153	.037	-.201

***p* < .01, **p* < .05

5.5 Hypotheses related to Sporting Success

H_{15}, H_{16} & H_{17}: *A positive correlation between success in judo and scores on mental toughness questionnaires was expected. 2D:4D and sporting success were expected to show a negative correlation. No association between HGS and sporting success was expected in the current study*.

The MTQ48 and SMTQ scores were positively correlated with sporting success for both men and women with larger associations for the female participants. The TROSCI scores as well as the digit ratios were negatively related to sporting success for all athletes, but none of the correlations reached statistical significance. HGS was positively related to success, but the only significant associations were found for women in this sample. These findings are summarized in Table 17.

Table 17 correlations with sporting success

sex	MTQ 48	SMTQ	TROSCI	RSES	BPAQ	BMI	Left 2D:4D	Right 2D:4D	Left HGS	Right HGS
Male (*N* = 94)	.230*	.152	-.045	.254*	-.188	.095	-.047	-.027	.189	.136
Female (*N* = 46)	.399**	.401**	-.188	.563***	-.294*	.302*	-.026	-.120	.406**	.387**

***p < .001, **p < .01, *p < .05

H_{18}: *Sporting success for judo athletes can be predicted by a dominance model with five blocks containing variables associated with success. The variables, which were chosen because of their significant correlations (Table 17) with sporting success, are BMI, experience and training, mental toughness and self esteem, hand-grip strength, and aggression. The TROSCI and the 2D:4D measurements were excluded from the analysis as the results indicate that they are unrelated to success.*

Experience was a factor score calculated from participants' age and years of practicing judo. The mental toughness and self-esteem factor score included the

MTQ48, SMTQ and RSES total scores and the hand-grip strength factor score calculated from the average left and right hand HGS. Aggression was included as the BPAQ total score.

The benefit of performing a dominance analysis instead of a multiple regression is that the sequence in which the variables are introduced in the model is irrelevant. The r^2 value is calculated for every possible combination of the variables in order to find out about the relative importance of all variables and not just their global importance (Budescu & Azen, 2004). With this method, it is possible to mathematically determine the relative importance of predictors instead of deciding on a specific order in advance, as is the case with multiple regression (Budescu, 1993).

The dominance analysis in this study was calculated separately for men and women. The model for males is presented in Table 18 and the model for female participants can be viewed in Table 19. Of the total variance, 29.7% for males and 54.1% for females were explained by the model. The absolute shares of the individual variables are depicted as general dominance. The rescaled dominance signifies the relative importance of the variables between themselves. For the male participants in this study, the “experience & training” variable is the most influential in this model, explaining 78.9% of the rescaled dominance, followed by the “MT factor” with 9.3%. The remaining variables (BMI, HGS, BPAQ) make up between 3% and 6% each. For the women in this study, the “experience & training” variable is the most important variable in the model as well, with a rescaled dominance of 46.3%. It is followed by the “MT factor” with 27.8% and HGS with 10.3%. The BPAQ variable is responsible for 8.7% of the rescaled dominance and the BMI is the least important factor explaining only 6.9% in this model.

Table 18 Dominance analysis for sporting success (males, *N* = 94)

k	BMI	Factorscore Experience, Training	Factorscore MT	Factorscore HGS	BPAQ
0	.0090	.2630	.0590	.0280	.0350
1	.0045	.2395	.0353	.0115	.0188
2	.0070	.2285	.0223	.0053	.0123
3	.0108	.2228	.0140	.0027	.0097
4	.0130	.2180	.0070	.0000	.0080
General Dominance	.0088	.2344	.0275	.0095	.0168
Rescaled Dominance	2.9798	78.9057	9.2649	3.2043	5.6453

Table 19 Dominance analysis for sporting success (females, *N* = 46)

k	BMI	Factorscore Experience, Training	Factorscore MT	Factorscore HGS	BPAQ
0	.0910	.3930	.2810	.1690	.0860
1	.0490	.2888	.1845	.0768	.0595
2	.0248	.2238	.1255	.0270	.0403
3	.0138	.1863	.0920	.0067	.0283
4	.0080	.1610	.0690	.0000	.0200
General Dominance	.0373	.2506	.1504	.0559	.0468
Rescaled Dominance	6,8977	46,3155	27,8004	10,3327	8,6537

6 Discussion

In the following section the results (see chapter 5) of this study will be discussed relating to the hypotheses and the results from previous research. Moreover, limitations of the study and implications for future research will be addressed.

6.1 Measuring Mental Toughness

Overall internal consistencies were satisfying for all questionnaires. Out of the four subscales which were found to have poor internal consistency (MTQ48 challenge and control, SMTQ constancy and control), three corresponded with the results from another study that compared these questionnaires (Crust & Swann, 2011). Another similarity to previous results is the negative discriminatory power of MTQ48 item 34 ("*I generally hide my emotions from others*") which was also detected in this study. The only other MTQ48 item with a negative discriminatory power in this study was item 26 ("*when I am angry or annoyed, I usually let others know about it*"). As both items are part of the control scale, it could be considered to modify or exclude them in future studies to improve the internal consistency of this scale.

One of the primary goals of this study was to check the proposed factor structure of three different mental toughness questionnaires (MTQ48, STMQ, TROSCI). For that purpose an exploratory as well as a confirmatory factor analysis was conducted for all questionnaires.

The exploratory factor analysis reported 16 factors with an eigenvalue greater than 1 for the MTQ48. The inflexion in the screeplot indicates a structure with three factors explaining 31% of the total variance, as opposed to the four factor structure suggested by the authors (Clough et al., 2002). For the SMTQ, graphic analysis corresponded with Kaiser's criterion, by yielding four factors explaining 58% of the variance. That is one additional factor as compared to the original model (Sheard et al., 2009). The results for the TROSCI showed three factors using Kaiser's criterion, but the screeplot confirmed the one-factor structure that was originally suggested (Beattie et al., 2011).

The CFA was conducted for the original models of the SMTQ and the TROSCI as well as the alternative MTQ48 and SMTQ models which were

indicated by the exploratory factor analysis. All fit indices for each questionnaire are outside of acceptable limits. It is unclear why no fit could be computed for the original version of the MTQ48, but this finding as well as the rather poor fit of the alternative 3-factor model further support the need to rethink theoretical framework and the factor structure of this questionnaire. The results indicate that the factor structure of MTQ48, SMTQ and TROSCI is still a controversial issue and that further research is needed to reach a consensus with acceptable psychometric properties.

The correlation of .68 between MTQ48 and SMTQ was about as high as expected and the correlations between corresponding subscales were of moderate size (.46-.63) and also higher than those of subscales measuring different traits (.27-.42). These results indicate that the corresponding subscales might actually measure similar traits, but even though the expected associations were slightly larger, the correlations between non-corresponding subscales were still significant and too high to discriminate properly between the different subscales.

When comparing the mental toughness questionnaires with each other and with the RSES, findings were contradictory to the hypothesis that self-esteem would present weaker relations to mental toughness as opposed to relations of the different MT questionnaires among themselves. The self-esteem questionnaire showed higher correlations with MTQ48 (r = .62) and SMTQ (r = .66) than the TROSCI did. This may be due to the fact that self-esteem is more similar to mental toughness than expected. Also, the TROSCI seems to be more closely related to the SMTQ (r = .61) than to the MTQ48 (r = .48). In agreement with the hypothesis, a significant relationship between the mental toughness and judo experience could be found for the MTQ48 and the SMTQ, supporting previous research (Nicholls et al., 2009).

6.2 The Role of Aggression in the Context of Judo

With regard to the relationship of judo practice and aggression, the results show a distinct negative relation between years of judo experience and self-reported aggression. The direction is the same for all BPAQ scales. The anger and the physical aggression score show the strongest negative correlations, which indicates that judoka with more experience seems to be less angry and less physically aggressive. This outcome confirms former results (Lamarre & Nosanchuk, 1999).

As expected, verbal aggression seems to be unrelated to either mental toughness or self-esteem, whereas associations with physical aggression are small but consistently negative. In contrast to these variables, the total aggression and the hostility subscale showed unexpectedly strong negative correlations to mental toughness and self-esteem varying between -.14 and -.32 for the total score and -.25 and -.49 for hostility. These findings might be interesting in an investigation regarding whether mental toughness and self esteem could be a protective factor for aggressive behavior and bullying in teenagers and young adults. Also, as suggested by the negative relationship of judo experience and aggression, special judo classes with a focus on personality development could be helpful for youth with behavioral problems (Palermo et al., 2006; Twemlow et al., 2008).

Another interesting finding in this study is that self-reported aggression seems to be negatively related to being a successful judoka. This trend was visible for both sexes but it was more pronounced for women (r = -.29). As there was no control group, no differences between judoka and the general population can be reported in this study. However, the results indicate, that within the group of judoka, the more experienced and more successful athletes are also less aggressive. This would contradict the hypothesis that martial arts practice makes athletes more aggressive (Reynes & Lorant, 2004; Wargo et al., 2007).

6.3 2D:4D and Hand-Grip Strength

The results regarding 2D:4D digit ratio (see chapter 5.3) show the expected sexual dimorphism, with males having significantly lower ratios than female participants in both hands (Fink et al., 2003; Manning, 2002a). Moreover, considering the age of the participants, they seem to support the hypothesis that digit ratio is rather stable throughout childhood and puberty (McIntyre et al., 2005; Trivers et al., 2006).

Compared to the general Austrian population, male as well as females athletes in this sample had significantly lower 2D:4D in both hands, which might indicate that judoka tend to have higher fetal testosterone levels than the general population. The positive relation between 2D:4D and BMI (Fink et al., 2003) could be confirmed regardless of gender, but it only reached statistical significance for left hand 2D:4D in males.

To shed more light on a possible relationship between digit ratio, aggression, and gender, all BPAQ subscales were included in the analysis. It should be noted that none of the correlations reached statistical significance. Nevertheless, it is important to point out that there was a negative trend between both hands and all BPAQ scores in males, whereas female results display a positive trend for both hands and all BPAQ scores. For future research, this study's results might indicate that although no significant relationship between aggression and 2D:4D could be found here, a possible association might point different directions for men and women.

The expected sex differences were found for hand-grip strength, and signs of fatigue could only be reported for females' left hands. For males as well as females, HGS was unrelated to 2D:4D which contradicts former findings for men (Fink et al., 2006), but supports former findings for women (van Anders, 2007). In this sample, only one significant positive correlation (males' left hand) could be found between HGS and training intensity, indicating that judo training does not specifically enhance HGS in general, but may aim at compensating left hand weaknesses since judo athletes need to use both hands equally. This hypothesis could also be supported by the fact that in this predominantly right-handed sample differences in HGS between right and left hand were 2.2 kg for men and 1.2 kg for women, which equals only about 5% / 4% compared to the 10% which are usually

found in right handed people (Petersen et al., 1989; as cited in Gallup et al., 2007, p.424).

Contradictory to expectations and former research (Gallup et al., 2007), a significant negative relationship between HGS and self-reported aggression could be found for the male participants in this study. For females, the relationship also pointed in a negative direction, but failed to reach statistical significance. This is an interesting finding, which could be further investigated by comparing the HGS-aggression relationship in different kinds of athletes or between athletes and the general population.

6.4 Predicting Sporting Success

A dominance analysis approach was chosen instead of a hierarchical multiple regression model, which was used in previous research (Tester & Campbell, 2007; Voracek et al., 2010). This method has the advantage of making the sequence of variables in the model irrelevant, and it also computes a rescaled dominance of the predictors in addition to the general dominance (Budescu, 1993; Budescu & Azen, 2004). A total of five blocks (1:BMI, 2: experience & training, 3: MT & self-esteem, 4: HGS, 5: aggression) was chosen for this model, and only variables that correlated significantly with success were included, because unrelated variables were not expected to explain any variance. Disagreeing with other results (Tester & Campbell, 2007; Voracek et al., 2010), left and right hand 2D:4D were unrelated to sporting success in this sample, so these variables were excluded from the dominance analysis. Corresponding with the outcome of several other studies (Franchini, Miarka et al., 2011; Franchini et al., 2005; Sanchez et al., 2011), no significant relationship between isometric HGS and success in judo could be found for men, but female participants displayed a significant positive relationship, which supports the findings of Sanchez et al. (2011). This raises the question of what is causing this difference between the sexes.

Overall, the model seemed to have a better fit for females, explaining 54% of the variance but explaining only 30% for males. The most prominent predictor was experience and training in both cases. For men, this predictor explained 79% of the rescaled dominance, with mental toughness following with 9% and BMI, HGS, and aggression explaining the remaining 12%. For women, experience and training was less important than for men with a rescaled dominance of 46%, whereas mental toughness and self esteem seemed to be more important (28%) for success. The three remaining predictors HGS, aggression, and BMI explained 10%, 9% and 7%, respectively.

Taking a look at the general dominance, the results indicate that experience and training seem to be equally important for male and female judoka, explaining roughly 25% of the total variance. All remaining variables, especially the MT factor, were of greater importance when predicting success for female participants. An interesting aspect for future research is whether mental toughness training is more important for female than for male athletes. Another major challenge will be the

identification of other factors influencing sporting success, as particularly the male model still contains 70% of unexplained variance.

One limitation of this study with regard to sex differences was the unbalanced sample size of males and females. A larger and balanced sample would be preferable for further investigations on this subject. Also, the indicators used for sporting performance were self-reported and retrospective, as there are no Austrian national rankings in judo. This could have been a source of bias and a more objective measure could help to reduce this problem.

7 Conclusion and Ideas for Future Research

The primary goal of this study was to contribute to the ongoing discussion of mental toughness and its measurement. This aim was realized in the unique context of judo. Three different questionnaires were used and compared to each other. Further, special attention was devoted to putative markers of prenatal testosterone, namely 2D:4D digit ratio and hand-grip strength. In addition, it was focused on aggression as a personality trait which might be especially relevant for martial arts.

Data were collected from 140 judo athletes (94 males, 46 females). They were asked to complete five questionnaires as well as a personal information sheet (sex, age, weight, height, nationality, handedness, judo belt, competition level, years of experience, weekly training hours) and isometric hand-grip strength as well as digit ratio was measured.

Based on the results of this study, further research on the measurement instruments of mental toughness, especially on the MTQ48, is suggested to eliminate weaknesses and improve correlations between corresponding scales as well as model fit. Further, the similarities between self-esteem and mental toughness were stronger than expected, so it must still be clarified whether these questionnaires are actually measuring different traits. In this sample of judoka, mental toughness and self-esteem were clearly and negatively related to aggression and especially hostility. So it might be an intriguing question for future research to find out whether mental toughness and self esteem could be a protective factor for aggressive behavior and bullying in teenagers and young adults.

Another interesting finding of this study was that more successful judoka seem to be significantly less aggressive than their colleagues. This result, which was especially pronounced for females, provides evidence against the hypothesis that martial arts practices makes athletes more aggressive. Since most previous studies on this subject were conducted with male participants only, future research should particularly investigate the effects of success on female martial artists' aggression.

2D:4D digit ratio was characteristic for men and women as well as athletes compared to the general population, but none of the predicted relations to hand-grip strength, sporting success or aggression could be confirmed. Hand-grip strength however presented some marked and sometimes unexpected relationships. The correlation to success could be confirmed for women only and it was also the 3rd most important predictor in the dominance analysis on judo success. Surprisingly, a strong negative relationship with aggression was found which strongly suggests further inquiry on this topic. To find out, whether this effect is unique for judoka, studies with different kinds of athletes and comparisons to the general population should be conducted.

Regarding the dominance analysis models for sporting success, the model explained considerably more of the total variance for women than it did for men. This leads to the assumption that there are other factors influencing male judoka's success which have not been taken into account in this study. Finding these variables is an important challenge for future studies on this topic. Apart from this, the most interesting result of the dominance analysis is the fact that mental toughness and self-esteem follow right behind experience and training when it comes to predicting sporting success.

These results add to a growing body of evidence of mental toughness research and support the strong belief of coaches and athletes in the impact of mental toughness.

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9 Eidesstattliche Erklärung

Ich bestätige, die vorliegende Diplomarbeit selbst und ohne Benutzung anderer als der angegebenen Quellen verfasst zu haben. Weiters ist sie die Erste ihrer Art und liegt nicht in ähnlicher oder gleicher Form bei anderen Prüfstellen auf. Alle Inhalte, die wörtlich oder sinngemäß übernommen wurden, sind mit der jeweiligen Quelle gekennzeichnet.

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