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A behavioural genetic study of mental toughness and personality

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ABSTRACT

The present study is the first behavioural genetic (BG) investigation of mental toughness, as measured by the 48-item mental toughness (MT48) questionnaire, and the first BG investigation of relationships between mental toughness and the Big-5 factors of personality. Participants were 219 pairs of adult monozygotic and dizygotic twins from across North America. Twin study methodology was used to determine the extent to which genes and/or environmental factors contributed to individual differences in mental toughness and also to determine the genetic and/or environmental basis of any relationship between mental toughness and personality. Univariate BG analyses revealed that individual differences in mental toughness (as well as in personality) were largely attributable to genetic and nonshared environmental factors. Bivariate BG analyses revealed that phenotypic correlations between mental toughness and personality were largely attributable to common genetic and common nonshared environmental factors.

1. Introduction

Behavioural genetic (BG) studies investigate the extent to which genetic and environmental factors contribute to individual differences in behavioural traits. The aim in conducting the current research is to determine the genetic and environmental influences on a relatively newly defined construct termed mental toughness and also to investigate relationships between mental toughness and the Big-5 personality traits at the phenotypic, genetic, and environmental levels.

1.1. Mental toughness

Mental toughness has recently been defined by Clough, Earl, and Sewell (2001). These researchers developed a definition of mental toughness based on the established psychological concept known as the 'hardy personality' that was first proposed by Kobasa (1979). Hardiness consists of three main components: *control*, the ability to feel and act as if one is in control of various life situations; *commitment*, the tendency to involve rather than distance oneself from whatever one is doing; and *challenge*, the ability to understand that change is normal.

Clough et al. (2001) collected qualitative information from athletes and were able to categorize most of the factors the athletes identified as necessary for one to be mentally tough into Kobasa's (1979) hardiness model; however, there were some elements that did not apply to any of the three hardiness categories. As a result, Clough et al. (2001) determined that a mental toughness model requires a fourth category: *confidence*. The researchers note that "confidence is an important factor relating to sport performance [and one that] has not been considered as a distinct element in previous models of hardiness" (p. 38). As such, Clough et al. (2001) created what they call the '4Cs model of mental toughness': control, commitment, challenge, and confidence. The definition these researchers have developed by gathering evidence from research, athletes, coaches, and sport psychologists is as follows:

> Mentally tough individuals tend to be sociable and outgoing; as they are able to remain calm and relaxed, they are competitive in many situations and have lower anxiety levels than others. With a high sense of self-belief and an unshakeable faith that they control their own destiny, these individuals can remain relatively unaffected by competition or adversity (p. 38).

Clough et al. (2001) also developed a 48-item mental toughness questionnaire (the MT48) that provides an overall score of mental toughness and scores on the 4C's subscales. Based on data collected from 600 athletes, Clough et al. (2001) reported that the reliability of this scale was .90. Although mental toughness is related to the older construct of hardiness, studies have demonstrated that they are nonetheless distinct: the main difference being that mental toughness, in particular as measured by the MT48, represents an extension of hardiness with its assessment of confidence in addition to control, challenge, and commitment (Clough et al., 2001; Golby & Sheard, 2004).

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1.2. Personality

Although many models of personality have been proposed (Eysenck & Eysenck, 1969; McCrae & Costa, 1989; Tellegen, 1985), currently, the most widely accepted is the 'Big-5 theory' proposed by Costa and McCrae (1992). The Five Factor Model includes extraversion, agreeableness, conscientiousness, openness to experience, and neuroticism. These five factors of personality have been found to account for the majority of individual differences that exist between people in most personality traits (Costa & McCrae, 1992).

Most studies have demonstrated that genes and nonshared environmental factors account for the majority of individual differences among people in personality (Loehlin, 1992). In fact, research has shown that individual differences in almost all facets of the Big-5 factors of personality can be explained by genetic and nonshared environmental influences (Jang, Livesley, Angleitner, Riemann, & Vernon, 2002). Plomin, DeFries, and McClearn (1990), estimate that the average heritability for any given personality trait is approximately 50%.

1.3. The current study

The current study uses the MT48 questionnaire to define and measure mental toughness. This study will determine the extent to which genes and/or environmental factors contribute to the development of individual differences in mental toughness. Although prior BG studies have reported a genetic component to constructs related to mental toughness, such as behavioral resilience, cognitive resilience to socioeconomic deprivation, and task persistence (Deater-Deckard, Petrill, Thompson, & DeThorne, 2006; Kim-Cohen, Moffitt, Caspi, & Taylor, 2004), no previous BG research has examined the multiple dimensions of mental toughness identified by Clough et al. (2001). Moreover, the current study goes beyond estimating the contribution of genetic and environmental factors to individual differences in mental toughness by also determining whether any phenotypic correlations between mental toughness and personality are themselves attributable to correlated genetic and/or environmental factors.

Clough et al. (2001) assert that "mentally tough individuals tend to be sociable and outgoing" (p. 38). Given this description, and the fact that studies have shown significant positive associations between hardiness, resiliency, and extraversion (Campbell-Sills, Cohan, & Stein, 2006; Maddi, Harvey, Lu, Persico, & Brow, 2006), it is expected that mental toughness will be positively correlated with extraversion. Also from Clough et al's (2001) definition, it is expected that a positive correlation will be found between mental toughness and agreeableness and conscientiousness: people who are "relatively unaffected by competition or adversity" may also be viewed as being agreeable; and those who believe they "control their own destiny" or who score high on Commitment are likely to also be conscientious. Clough et al. (2001) also state that individuals high on mental toughness experience low anxiety and have a high sense of self-belief; from this, it is expected that a negative correlation will be found between mental toughness and neuroticism. Again, previous studies have reported significant negative correlations between hardiness, resiliency, and neuroticism (Campbell-Sills et al., 2006; Maddi et al., 2002), although others have noted that the relationship between hardiness and neuroticism is not so pronounced as to render the two constructs redundant (Benishek & Lopez, 1997; Campbell-Sills et al., 2006; Maddi et al., 2002; Sinclair & Tetrick, 2000). Finally, at the component level, it is predicted that there will be a positive correlation between challenge and openness to experience because both constructs reflect an appreciation for new experiences. Based on previous behavioural genetic studies of other personality traits, it is expected that any observed phenotypic correlations between mental toughness and personality will primarily be attributable to common genetic and common nonshared environmental factors.

2. Method

2.1. Participants

Participants were 152 pairs of monozygotic (MZ) and 67 pairs of dizygotic (DZ) adult twins. There were 438 participants in total comprising 30 pairs of male MZ twins, 122 pairs of female MZ twins, eight pairs of male DZ twins, and 59 pairs of female DZ twins. The participants ranged in age from 18 to 82 years ($M = 23.88$, SD = 6.22). The twins were recruited from newspaper advertisements placed in newspapers and magazines across North America. Initial contact was made by the twins and they provided their contact information to become participants in an ongoing mail-based twin study. More than 95% of twins who made initial contact subsequently agreed to participate in this study.

2.2. Measures

A 16-item zygosity questionnaire (Nichols & Bilbro, 1966) was used which asks questions about the twins' physical similarity (e.g., height, eye color, and general appearance) and the frequency with which they are mistaken for one another by other family members and friends. This questionnaire has been shown to be at least 93% as accurate as red blood cell polymorphism analyses for determining zygosity (Kasriel & Eaves, 1976).

Twins also completed the 240-item NEO-PI-R which uses a five point Likert scale to assess the Big-5 factors of personality: extraversion (E), neuroticism (N), openness to experience (O), agreeableness (A), and conscientiousness (C). Internal consistency reliabilities of the scales are: N .92, E .89, O .87, A .86, and C .90 (Costa & McCrae, 1992).

Finally, the participants completed the MT48: a 48-item questionnaire that assesses mental toughness on a five point Likert scale. The MT48 provides an overall score for mental toughness as well as scores for each of four subscales of mental toughness: challenge, commitment, confidence, and control (Clough et al., 2001). Confidence and control themselves also have two subsets: Confidence (abilities and interpersonal) and control (emotion and life). Example items of the scales are: Challenges usually bring out the best in me (challenge), I do not usually give up under pressure (commitment), I am generally confident in my abilities (confidence-abilities), I am comfortable telling people what to do (confidence-interpersonal), I can usually control my nervousness (control-emotion), and I generally feel in control (control-life). In our samples, the reliabilities (coefficient alphas) of these scales range from .74 (challenge and control) to .92 (overall mental toughness).

2.3. Procedure

The participants in this twin study had been sent two packages of questionnaires since they first agreed to participate. The first mail-out included the zygosity questionnaire and the NEO-PI-R questionnaire. The mental toughness questionnaire (MT48) was included in the most recent second package of questionnaires sent to the twins. In both mail-outs, participants were mailed a letter of information, a pencil, a self addressed and stamped envelope, as well as a package of questionnaires and instructions. The participants were asked to complete the questionnaires at their own pace, in the privacy of their own homes, and separately from their

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twin. All participants who returned their packages were sent debriefing forms outlining the details of the study and were thanked for their participation. Participants were also compensated $25.00 and $30.00 respectively for each of the packages returned. Finally, for each package of questionnaires returned, participants were entered into separate draws to win one of ten $100.00 cash prizes.

2.4. Analysis

Most of the twins completed all of the items on all of the questionnaires but occasionally an item was left blank. Missing data were handled by using the average of the Likert scale. The 48 items of the MT48 were converted into nine scores: an overall mental toughness score, the four subscales of mental toughness, as well as the two subscales for each of confidence and control. The 240 items of the NEO-PI-R were converted into five scores, one for each factor of personality. Pearson correlations were computed separately among MZ and DZ twins in order to assess the degree of similarity between the twins on their mental toughness and personality scores.

Univariate BG model fitting was carried out using the software package Mx (Neale, Boker, Xie, & Maes, 2006). Mx uses structural equation model fitting to estimate the extent to which genetic (A), shared environmental (C), and nonshared environmental (E) factors contribute to individual differences. Although reduced models (for example, AE, CE, and E only) can also be fit, Sullivan and Eaves (2002) strongly argue that in analyses based on discrete traits, estimates from the full ACE model will be more accurate, and that attempts at reporting reduced models result in oversimplification of the models rather than a simpler and more accurate representation of the data.

Bivariate BG analyses were also performed using the software package Mx (Neale et al., 2006). These analyses estimate the extent to which observed phenotypic correlations between variables are attributable to common genetic and/or common environmental influences by examining the cross-correlations (across variables) within a twin pair by the method of Cholesky or triangular factor analysis (Neale & Cardon, 1992). In conducting these analyses, a full ACE model is tested as well as reduced AE and CE models: the model with the lowest chi-square value and lowest AIC value is chosen as the best fitting model. For each of the correlations reported in Tables 2 and 3, the AE model was found to have the best fit, resulting in estimates of genetic (rg) and environmental (re) correlations.

3. Results

Clough et al. (2001) did not report conducting any factor analyses of the MT48, so we conducted exploratory and confirmatory factor analyses on our data to test the presence of the four factors that the scale was developed to measure. Twins within each pair were arbitrarily designated as "twin 1" and "twin 2" and exploratory analyses were performed separately among all the "twin 1's" and then among all the "twin 2's" in order to have independent observations. In each of these analyses the scree plots suggested four factors, accounting for 40% and 42% of the variance, respectively, corresponding to control, commitment, challenge, and confidence. Because these factors were correlated, confirmatory factor analyses were then performed to compare one and four-factor solutions. The four-factor solution provided a better fit to the data than did a single factor. Following oblimin rotation, the pattern matrix suggested that the items fit moderately well onto their designated factors and, based on this, we calculated nine mental toughness scores for use in the following BG analyses: an overall mental toughness score, scores on the four subscales of mental toughness, and scores on the two subscales for each of confidence and control.

Shown in Table 1 are the MZ and same-sex DZ twin correlations for the nine mental toughness scales and the Big-5 factors of personality. Also shown are genetic and environmental parameter estimates derived from univariate behavioural genetic model-fitting analyses. Individual differences in all mental toughness variables except the subscale 'control over life' can be fully accounted for by additive genetic (a^2) and nonshared environmental factors (e^2). Shared environmental factors make a very small (and non-significant) contribution to 'control over life'. As can be seen, heritability estimates for the mental toughness variables range from .36 to .56, while unique environmental estimates range from .44 to .64. Also examined were the univariate model-fitting analyses for the Big-5 factors simply to demonstrate that these would show the pattern of results that is typically found for these variables. As expected, individual differences in the five factors of personality show a negligible influence of the shared environment and are instead largely attributable to genetic and nonshared environmental factors.

Shown in Table 2 are the phenotypic correlations (rp) among the nine mental toughness variables. Also shown are the genetic (rg) and nonshared environmental (re) correlations and their 95% confidence intervals. At the phenotypic level, all correlations were significant at the .01 level. These phenotypic correlations range from .15 (interpersonal confidence and control over life) to .91 (confidence in abilities and emotional control). The majority of the correlations are very strong, with 23 of 36 correlations greater than .60 and 10 greater than .80.

Genetic and environmental correlations whose 95% confidence interval does not include zero are significant at the .05 level. All genetic correlations among the nine mental toughness variables were significant except that between interpersonal confidence and

Table 1
Twin correlations (*r*), parameter estimates, and confidence intervals for the nine mental toughness variables and the five factors of personality

	MZr	DZr	a^2 (95% CI)	c^2 (95% CI)	e^2 (95% CI)
Mental toughness scales					
Challenge	.47	−.04	.43 (.18 to .54)	.00 (.00 to .20)	.57 (.46 to .71)
Commitment	.37	.11	.36 (.00 to .48)	.00 (.00 to .34)	.64 (.52 to .78)
Control	.49	.15	.47 (.14 to .58)	.00 (.00 to .29)	.53 (.42 to .66)
Emotional control	.56	.08	.56 (.36 to .66)	.00 (.00 to .15)	.44 (.34 to .57)
Control over life	.44	.24	.38 (.00 to .56)	.06 (.00 to .45)	.56 (.45 to .70)
Confidence	.45	.14	.44 (.09 to .55)	.00 (.00 to .30)	.56 (.44 to .69)
Confidence in abilities	.52	−.04	.49 (.32 to .61)	.00 (.00 to .13)	.51 (.39 to .64)
Interpersonal confidence	.49	.28	.52 (.12 to .62)	.00 (.00 to .34)	.48 (.38 to .62)
Mental toughness	.54	.05	.52 (.30 to .62)	.00 (.00 to .18)	.48 (.38 to .61)
Personality scales					
Neuroticism	.58	.18	.56 (.36 to .64)	.00 (.00 to .18)	.44 (.36 to .53)
Extraversion	.49	.28	.43 (.07 to .57)	.06 (.00 to .38)	.51 (.43 to .61)
Openness to experience	.65	.32	.65 (.42 to .71)	.00 (.00 to .21)	.35 (.29 to .43)
Agreeableness	.48	.27	.44 (.08 to .57)	.04 (.00 to .36)	.52 (.43 to .62)
Conscientiousness	.46	.17	.47 (.25 to .56)	.00 (.00 to .19)	.53 (.44 to .63)

MZr = monozygotic correlation; DZr = dizygotic correlation; a^2 = additive genetic effects; c^2 = common environment effects; e^2 = unique environment effects; 95% CI = 95% confidence interval.

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Table 2
Multivariate genetic analyses of the nine mental toughness scale scores

	Challenge	Commitment	Control	Emotional control	Control over Life	Confidence	Interpersonal confidence	Mental toughness
Commitment	rp = .59** rg = .78 (.60 to .93) re = .48 (.35 to .58)							
Control	rp = .64** rg = .84 (.71 to .94) re = .52 (.40 to .62)	rp = .65** rg = .69 (.50 to .82) re = .64 (.55 to .73)						
Emotional control	rp = .63** rg = .79 (.66 to .90) re = .47 (.34 to .58)	rp = .61** rg = .80 (.65 to .93) re = .51 (.39 to .62)	rp = .68** rg = .76 (.63 to .87) re = .57 (.46 to .66)					
Control over life	rp = .47** rg = .57 (.36 to .74) re = .40 (.27 to .52)	rp = .40** rg = .36 (.09 to .58) re = .40 (.26 to .52)	rp = .84** rg = .85 (.76 to .92) re = .81 (.75 to .86)	rp = .43** rg = .43 (.21 to .61) re = .31 (.17 to .44)				
Confidence	rp = .61** rg = .88 (.75 to 1.00) re = .42 (.29 to .54)	rp = .70** rg = .83 (.68 to .94) re = .64 (.54 to .72)	rp = .84** rg = .85 (.76 to .92) re = .81 (.75 to .85)	rp = .72** rg = .90 (.80 to .99) re = .59 (.48 to .69)	rp = 42** rg = .48 (.25 to .68) re = .32 (.18 to .44)			
Confidence in abilities	rp = .61** rg = .81 (.67 to .93) re = .46 (.33 to .57)	rp = .57** rg = .74 (.57 to .88) re = .51 (.39 to .62)	rp = .73** rg = .86 (.74 to .95) re = .58 (.47 to .68)	rp = .91** rg = .95 (.91 to .97) re = .88 (.83 to .91)	rp = .53** rg = .60 (.41 to .77) re = .35 (.21 to .48)	rp = .70** rg = .87 (.75 to .97) re = .59 (.48 to .68)		
Interpersonal confidence	rp = .45** rg = .61 (.42 to .77) re = .30 (.15 to .43)	rp = .47** rg = .71 (.50 to .91) re = .29 (.15 to .43)	rp = .39** rg = .49 (.28 to .67) re = .29 (.14 to .42)	rp = .80** rg = .88 (.80 to .93) re = .74 (.66 to .80)	rp = 15** rg = .09 (−.16 to .32) re = .12 (−.03 to .27)	rp = .51** rg = .76 (.60 to .91) re = .35 (.21 to .48)	rp = .48** rg = .67 (.50 to .81) re = .34 (.19 to .47)	
Mental toughness	rp = .80** rg = .92 (.85 to .98) re = .71 (.62 to .78)	rp = .82** rg = .88 (.79 to .95) re = .82 (.76 to .86)	rp = .88** rg = .91 (.85 to .95) re = .85 (.80 to .89)	rp = .89** rg = .94 (.90 to .98) re = .82 (.76 to .86)	rp = .63** rg = .60 (.43 to .74) re = .59 (.48 to .68)	rp = .85** rg = .95 (.90 to 1.00) re = .78 (.71 to .83)	rp = .86** rg = .94 (.88 to .98) re = .79 (.71 to .83)	rp = .65** rg = .76 (.63 to .86) re = .53 (.41 to .63)

rp = Phenotypic (observed) correlation; rg = Genetic correlation; re = Environmental correlation; numbers in brackets represent the 95% confidence interval values; *$p < .05$; **$p < .01$ (two-tailed). *Note:* all relationships were best fit by an AE model.

control over life. These significant correlations ranged from .36 (control over life and commitment) to .95 (mental toughness and confidence). It is worth noting that 30 of 36 genetic correlations were greater than .60. Significant nonshared environmental correlations ranged from .29 (interpersonal confidence and confidence as well as interpersonal confidence and commitment) to .88 (confidence in abilities and emotional control). These correlations were generally smaller than the genetic correlations: only 11 out of 36 exceeded .60.

Shown in Table 3 are the phenotypic correlations (rp) between the nine mental toughness scales and the Big-5 variables. Also shown are the genetic (rg) and nonshared (re) environmental correlations between these variables and their 95% confidence intervals. As expected, many significant correlations were found. Some were quite low (e.g., .17 between commitment and openness to experience), but several others were high (e.g., −.64 between control and neuroticism, between confidence in abilities and neuroticism and between mental toughness and neuroticism). Of the 45 phenotypic correlations shown in Table 3, 40 were significant at the .01 level.

The bivariate model-fitting results indicate that the phenotypic correlations are attributable to correlated genetic and, to a lesser extent, to correlated nonshared environmental factors. Significant genetic correlations ranged from |.23| (commitment and openness to experience) to |.91| (control and neuroticism). Significant nonshared environmental correlations ranged from |.17| (interpersonal confidence and neuroticism) to |.47| (mental toughness and conscientiousness). As can be determined from their 95% confidence intervals, 32 of 45 genetic correlations and 32 of 45 nonshared environmental correlations were significant at the .05 level.

Nonshared environmental correlations between mental toughness and the Big Five factors were generally smaller than the corresponding genetic correlations. Thus, none of the nonshared environmental correlations in Table 3 exceeded .60 (the largest, between mental toughness and conscientiousness, was |.47|) and, in total, less than one half (17 of 45) fell in the moderate range between |.30| and |.60|. It is noteworthy that shared environmental factors did not contribute significantly to any phenotypic correlation.

4. Discussion

There were two goals in conducting the current research: first, to examine the extent to which genetic and environmental factors contribute to individual differences in a newly defined construct called mental toughness as measured by the MT48; second, to

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Table 3
Phenotypic correlations, genetic correlations and nonshared environmental correlations, and 95% confidence interval value between the nine mental toughness variables and the five factors of personality

Mental toughness scale	Neuroticism	Extraversion	Openness to experience	Agreeableness	Conscientiousness
Challenge	rp = −.47**	rp = .37**	rp = .29**	rp = .18**	rp = .27**
	rg = −.08 (−.62 to .97)	rg = .52 (.31 to .69)	rg = .39 (.21 to .56)	rg = .38 (.15 to .59)	rg = .37 (.10 to .61)
	re = −.21 (−.05 to −.34)	re = .26 (.12 to .40)	re = .20 (.05 to .35)	re = .03 (−.12 to .18)	re = .24 (.08 to .38)
Commitment	rp = −.42**	rp = .38**	rp = .17**	rp = .18**	rp = .52**
	rg = −.71 (−.49 to −.92)	rg = .42 (.18 to .63)	rg = .23 (.01 to .44)	rg = .40 (.16 to .65)	rg = .76 (.55 to .94)
	re = −.25 (−.10 to −.39)	re = .34 (.20 to .47)	re = .18 (.02 to .32)	re = .04 (−.11 to .19)	re = .43 (.30 to .54)
Control	rp = −.64**	rp = .26**	rp = .06	rp = .27**	rp = .36**
	rg = −.91 (−.78 to −1.00)	rg = .29 (.07 to .49)	rg = .12 (−.08 to .31)	rg = .56 (.36 to .76)	rg = .24 (−.02 to .46)
	re = −.42 (−.28 to −.54)	re = .22 (.07 to .36)	re = .07 (−.09 to .22)	re = −.01 (−.15 to .14)	re = .45 (.31 to .57)
Emotional control	rp = −.60**	rp = .50**	rp = .17**	rp = .08	rp = .31**
	rg = −.79 (−.65 to −.92)	rg = .65 (.48 to .78)	rg = .24 (.05 to .40)	rg = .13 (−.09 to .34)	rg = .24 (−.01 to .47)
	re = −.41 (−.27 to −.53)	re = .35 (.21 to .48)	re = .18 (.03 to .33)	re = .03 (−.12 to .18)	re = .35 (.20 to .49)
Control over life	rp = −.51**	rp = .02	rp = −.05	rp = .26**	rp = .20**
	rg = −.70 (−.52 to −.86)	rg = −.04 (−.28 to .19)	rg = .01 (−.18 to .22)	rg = .50 (.28 to .77)	rg = −.01 (−.29 to .24)
	re = −.33 (−.19 to −.46)	re = .07 (−.08 to .22)	re = −.08 (−.23 to .07)	re = .04 (−.11 to .18)	re = .32 (.18 to .46)
Confidence	rp = −.56**	rp = .41**	rp = .14**	rp = .20**	rp = .41**
	rg = −.86 (−.71 to −1.00)	rg = .55 (.35 to .72)	rg = .19 (−.02 to .38)	rg = .48 (.25 to 70)	rg = .49 (.24 to .70)
	re = −.35 (−.21 to −.48)	re = .29 (.14 to .42)	re = .20 (.04 to .34)	re = −.04 (−.19 to .11)	re = .38 (.24 to .51)
Confidence in abilities	rp = −.64**	rp = .38**	rp = .08	rp = .21**	rp = .33**
	rg = −.86 (−.72 to −.98)	rg = .52 (.32 to .69)	rg = .10 (−.10 to .29)	rg = .28 (.06 to .48)	rg = .22 (−.05 to .45)
	re = −.44 (−.31 to −.56)	re = .27 (.12 to .41)	re = .21 (.05 to .36)	re = .14 (−.02 to .28)	re = .40 (.25 to .52)
Interpersonal confidence	rp = −.35**	rp = .50**	rp = .23**	rp = −.13**	rp = .18**
	rg = −.52 (−.32 to −.72)	rg = .66 (.50 to .81)	rg = .35 (.16 to .52)	rg = −.11 (−.32 to .16)	rg = .25 (−.01 to .51)
	re = −.17 (−.02 to −.32)	re = .31 (.16 to .44)	re = .07 (−.08 to .23)	re = −.13 (−.28 to .02)	re = .12 (−.04 to .28)
Mental toughness	rp = −.64**	rp = .45**	rp = .18**	rp = .20**	rp = .43**
	rg = −.90 (−.77 to −1.00)	rg = .53 (.35 to .68)	rg = .26 (.07 to .43)	rg = .38 (.17 to .58)	rg = .39 (.16 to .60)
	re = −.41 (−.27 to −.53)	re = .37 (.23 to .49)	re = .18 (.03 to .33)	re = .03 (−.12 to .18)	re = .47 (.33 to .58)

rp = Phenotypic (observed) correlation; rg = Genetic correlation; re = Environmental correlation; numbers in brackets represent the 95% confidence interval values; *$p < .05$; **$p < .01$ (two-tailed). *Note:* all relationships were best fit by an AE model.

examine the extent to which mental toughness would correlate with the Big-5 personality dimensions and the extent to which any phenotypic correlations between these would be attributable to correlated genetic and/or correlated environmental factors.

4.1. Univariate analysis: the five factors of personality

Previous research has demonstrated that individual differences in all facets of the Big-5 factors of personality can be explained by genetic and nonshared environmental factors (Jang et al., 2002). Supporting evidence was found in this study. The heritability estimates for the Big-5 factors in the current study ranged from .47 to .56, which was consistent with a recent meta-analysis conducted on the heritability estimates for the Big-5 factors (Johnson, Vernon, & Feiler, 2008). These findings demonstrate that our sample of twins show the typical pattern of results for the Big-5 which, in turn, adds confidence to the validity of our other results.

4.2. Univariate analyses: mental toughness

It was expected and found that genetic and nonshared environmental factors would contribute to the development of individual differences in mental toughness. This trait then, is behaving in the same manner as virtually every personality trait that has ever been investigated in a behavioural genetic study (Johnson et al., 2008). The four subscales of mental toughness all showed a somewhat lower level of heritability than the overall mental toughness score, but individual differences in challenge, commitment, control, and confidence were nonetheless attributable to genetic and nonshared environmental factors.

These results may have implications for potential therapeutic interventions designed to modify an individual's level of mental toughness. Because traits that are mainly influenced by environmental factors may be more malleable than those mainly influenced by genetic factors, our findings suggest that it may be easier to help people increase only certain components of mental toughness rather than to increase their overall mental toughness. Research by Golby and Sheard (2006) has shown an association between serotonin transporter polymorphism and positive psychological attributes such as challenge and dispositional optimism; other studies have shown that increases in adrenaline levels from base rate during stressful situations lead to better social adjustment and emotional stability and imply that biological factors such as these can be influenced by conscious intervention and training (Dienstbier, 1989). This is clearly a topic in need of further experimental research.

4.3. Bivariate analyses: mental toughness scale scores

A series of bivariate analyses of the nine mental toughness scale scores were conducted to determine the phenotypic and genetic correlations among these variables. Phenotypic correlations were moderately strong and genetic correlations were very strong among the mental toughness variables. All significant genetic correlations except one (commitment and control over life) were stronger than the environmental correlations. Clearly, to the extent that the mental toughness variables are intercorrelated, these correlations are primarily attributable to the fact that those genes that contribute to one variable overlap substantially with the genes that contribute to the other variables.

4.4. Bivariate analyses: Mental toughness and the five factors of personality

It was expected that positive correlations would be found between all mental toughness variables and extraversion, openness

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to experience, agreeableness, and conscientiousness. It was also expected that negative correlations would be found between all mental toughness variables and neuroticism. The results of the current study support our initial hypotheses: all correlations between neuroticism and the nine mental toughness variables were significant, negative, and moderately strong, ranging from −.35 to −.64. This finding mirrors the way in which mental toughness has been defined. More specifically, Clough et al. (2001) state that mentally tough individuals are "calm and relaxed. . .and have lower anxiety levels than others" (p. 38). Those who score high in neuroticism, however, have a hard time coping with stressors and subsequently tend to suffer from anxiety (Costa & McCrae, 1992).

The results also support our hypothesis regarding correlations between the remaining mental toughness and Big-5 variables. More specifically, significant positive correlations between the nine mental toughness variables and extraversion, openness to experience, agreeableness, and conscientiousness were found, with just one exception: interpersonal confidence and agreeableness. The small negative correlation between these variables may reflect the fact that if an individual has strong interpersonal confidence, he or she may be less likely to agree with someone if their views do not match their own. In contrast, someone who has low interpersonal confidence may not feel confident enough in his or her own views to stand their ground and may instead be more likely to agree with others.

The current study also hypothesized that any observed phenotypic correlations between mental toughness and the five factors of personality would primarily be attributable to common genetic and nonshared environmental factors. Our hypothesis received strong support in this regard.

4.5. Limitations and conclusion

It is acknowledged that both mental toughness and the Big5 factors were measured with self-report questionnaires which may have contributed to spurious correlations between the variables. Also, in the context of the current study, it is possible that some pairs of twins may have completed questionnaires together and planned their answers accordingly. The twins were also self-selected. These limitations however, are shared by a large majority of twin studies and we do not expect that they have a significant biasing influence on our results.

This study provides insight into a newly defined construct called mental toughness; a trait many, especially those in the sports domain, have been attempting to strengthen for many years via coaching and training. The results of our study indicate that because mental toughness is quite heritable, it may be more difficult to strengthen or modify one's overall mental toughness than many people in the sports domain suggest. Instead, it may be easier to strengthen certain components of mental toughness such as commitment or control: the two subscales with the lowest heritabilities.

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