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The effect of stress, mental toughness, and their interaction on athletic and cognitive performance

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ABSTRACT

Athletes are regularly confronted with numerous challenges that contribute to elevated stress levels, which may interfere with optimal performance. Mental toughness (MT) is regarded as a crucial factor for athletic success, as it supports athletes in managing physical and psychological demands. Studies have reported positive associations between MT, adaptive coping strategies, reduced stress perception, and improved performance. The aim of the present study was to investigate the role of MT in moderating stress-performance relationship across three domains: physical endurance, cognitive performance, and isometric strength.

Participants underwent a crossover design with two measurement timepoints in a randomized, counterbalanced order. In the stress condition, stress was induced using the Trier Social Stress Test, whereas in the control condition a documentary film was watched; both conditions were followed by a performance test on a bicycle ergometer (Study 1; $n = 27$), or the d2-R Test of Attention (Study 2; $n = 27$), and an isometric handgrip endurance task (Study 3; $n = 28$). Stress reactivity was measured by physiological and psychological parameters. Repeated measures ANCOVAs were conducted to examine the influence of MT and coping strategies.

The results showed no significant interaction between MT and performance under stress. However, exploratory analyses indicated that athletes with higher MT used more problem-focused coping strategies, although no significant effect on performance was found across the three domains. These findings suggest that while MT is associated with coping preferences, its direct impact on the stress-performance relationship may depend on contextual factors, warranting further research in competitive settings.

1. Introduction

In the context of competitive sports, athletes are frequently exposed to high-pressure environments where peak performance must be achieved, despite the presence of significant stressors (for an overview, see Cooke et al., 2011). These demands require not only physical readiness but also psychological resilience (e.g., Gould et al., 2002; Liew et al., 2019). Among the psychological factors that contribute to optimal performance, mental toughness (MT) has emerged as a key construct associated with athletes' ability to remain focused, confident, and in control during stressful situations (e.g. Jones et al., 2002).

1.1. Mental toughness

MT is identified as an essential psychological resource for overcoming challenging and difficult circumstances, allowing athletes to cope better with demands in life or sports and to perform effectively under pressure (Jones et al., 2002; Loehr, 1994). MT has been conceptualized both as a stable trait and a more dynamic, state-like resource that evolves with experience (Gucciardi, 2020). Trait-based perspectives view MT as a stable psychological attribute that enables athletes to handle various physical, mental, and emotional demands (e.g., Clough et al., 2002; Gucciardi et al., 2009; Middleton et al., 2011). In this context, Clough et al. (2002) developed the 6Cs model of MT based on Kobasa's (1979) three-factor conceptualization of hardiness (challenge,

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commitment, and control with its subdimensions emotions and life) by adding confidence (with its subdimensions interpersonal and abilities) as a key component. Conversely, state-like perspectives describe MT as a flexible goal-directed psychological resource that can vary across situations and time (Gucciardi, 2017). This view indicates that MT is open to development and can be improved through experience and targeted interventions. Mentally tough individuals typically show perseverance after failure, sustained attention despite distractions, and effective stress regulation (Farnsworth et al., 2022; Gucciardi, 2017).

1.2. Mental toughness and its relation to stress

Stress and coping have been extensively studied within the trans-theoretical model proposed by Lazarus and Folkman (1984). According to their model, stress originates from a dynamic and interactive process between an individual and their environment. Stress arises when environmental demands exceed the individual's resources to cope. The model emphasizes two cognitive appraisal processes: primary appraisal (evaluating the significance of a situation) and secondary appraisal (assessing coping resources). When the situation is appraised as stressful, individuals initiate coping responses to manage the perceived imbalance (Kaiseler et al., 2009). Coping strategies are typically categorized into three types: Problem-focused coping (PFC) targets the stressor directly through planning or seeking information. Emotion-focused coping (EFC) aims to regulate the emotional response without altering the situation (e.g., seeking support, reframing). Avoidant coping (AC) involves disengagement strategies such as denial or distraction (Carver, 1997; Nicholls et al., 2008). Effective coping is crucial in athletic contexts, where success often depends on managing high-pressure situations (Lazarus, 2000).

MT appears to influence both the stress appraisal and coping responses. Athletes with higher overall MT are more likely to perceive stressors aschallenges rather than threats (Levy et al., 2012; Nicholls et al., 2012), fostering a proactive mindset and enhancing their performance. They also report lower levels of perceived stress intensity when faced with stressors (Gerber et al., 2013, 2018; Kaiseler et al., 2009), likely due to their emotional regulation skills and sense of control (Jones et al., 2007; Poulus et al., 2020). MT has been associated with the belief in one's ability to control one's own destiny (Nicholls et al., 2008) and with increased goal orientation and drive (Gould et al., 2002; Jones et al., 2007). Additionally, MT has been demonstrated to influence coping preferences (Kaiseler et al., 2009; Levy et al., 2012). Mentally tough individuals typically favor PFC strategies, often associated with better performance and stress management, while relying less on AC strategies, which can increase stress in the long term (Nicholls & Polman, 2007; Poulus et al., 2020). EFC may still play a supplementary role in helping athletes regulate emotions before employing PFC strategies effectively. However, the precise mechanisms by which MT shapes stress responses and influences coping behavior remain insufficiently understood.

1.3. Mental toughness and athletic performance

The relationship between MT and athletic performance has gained increasing interest in sports psychological research (for an overview, see Hsieh et al., 2023). While many studies report a positive relationship between MT and athletic performance (e.g., Guszkowska & Wójcik, 2021; Morais & Gomes, 2019), others have reported inconclusive findings (e.g., Brace et al., 2020; Cowden, 2016). Despite these mixed quantitative results, qualitative research consistently highlights MT as a crucial determinant of success among elite athletes (Gould et al., 2002; Liew et al., 2019). In his review, Cowden (2017) found that 77.8 % of the included studies reported better performance outcomes for athletes with higher levels of MT, who were also more likely to compete at advanced levels. Hsieh et al. (2023) confirmed a moderate to high correlation (r = .36) between MT and athletic performance in their meta-analysis. MT is especially important in endurance sports, where athletes must tolerate discomfort and maintain effort over prolonged periods of time. For instance, MT has been linked to improved race times in Olympic triathlon (Jones & Parker, 2019), marathon (Mahoney et al., 2014), and ultramarathon (Christensen et al., 2018). It also facilitates adaptive pacing strategies, allowing athletes to allocate their energy efficiently and push through fatigue (Weinberg & Gould, 2011; Zeiger & Zeiger, 2018). Beyond physical endurance, MT has been shown to enhance cognitive functions relevant to athletic performance. Mentally tough athletes demonstrate superior attentional focus and better resistance to distractions, supporting efficient decision-making and skill execution during high-level competitions (Weinberg et al., 2011). For instance, Roy et al. (2016) identified a positive relationship between MT and both agility and reaction ability in kho kho (a traditional tag game popular in India) athletes.

1.4. The present investigation

The primary aim of the three studies reported in this paper was to test the assumption that MT moderates the stress-performance relationship in different performance domains (Study 1: endurance performance on the cycle ergometer, Study 2: cognitive performance, Study 3: isometric handgrip endurance strength). Specifically, we aimed to determine whether individuals with lower MT levels experience performance decrements in stressful conditions, while those with higher levels of MT perform consistently under stress. Therefore, we investigated the following hypotheses in each of the three studies.

H1. Participants with lower levels of MT perform worse under stress than without stress.

Specifically, they were expected to perform worse i) on the bicycle ergometer (Study 1), ii) in the cognitive task (Study 2), and iii) in the isometric handgrip endurance task (Study 3).

H2. Participants with higher MT perform similarly in both conditions.

We assumed that higher levels of MT can support athletes to perform at their highest levels in the different performance tasks following a stress induction.

Furthermore, we performed exploratory analyses to investigate the association between MT and coping. Precisely, we wanted to find out which coping strategies would be used by mentally tough athletes and how the use of a specific strategy would influence the performance outcomes.

2. Methods

2.1. Participants

The objective of all three studies was to recruit diverse samples comprising individuals engaged in a range of sporting activities, representing varying performance levels, genders and age groups. Participants in the three studies were primarily sports science students aged 18 years and over. These students were recruited through personal contacts via advertisements in sports departments, in sports clubs, and on social media.

All participants provided informed consent before participation. All study procedures were in accordance with ethical principles of the Declaration of Helsinki and approval for each study was obtained by the local ethics committee (Ethics Committee of Faculty 5 Psychology and Sports Sciences at Goethe-University Frankfurt, project number: 2023–73) before the start of the study.

2.2. Design

Three preregistered studies (https://osf.io/tfzws/) were conducted at the universities' laboratories under standardized conditions. The same general design was implemented in each study, wherein participants were randomly assigned to an experimental and a control condition in a within-subjects design with two (Study 2) or three (Studies 1 and 3) measurement timepoints (order counterbalanced). However, a different performance outcome was assessed in each study (Study 1: endurance task on the cycle ergometer, Study 2: cognitive task, Study 3: isometric handgrip endurance task). In Studies 1 and 3, preliminary measurements were performed at the first measurement timepoint to establish an individual baseline for each participant for the respective endurance task.

In all three studies, stress was induced in the experimental condition by using the well-established Trier Social Stress Test (TSST; Kirschbaum et al., 1993), which comprises a simulated job interview and a subsequent arithmetic task. In the control condition, participants watched a standardized video documentary. In both conditions, physical (i.e., cortisol and heart rate) as well as psychological stress parameters (i.e., self-reported levels of anxiety and mood states) were measured as manipulation checks (see below). Due to the delayed cortisol response of the body, participants watched a 10-min video documentary after the TSST in the experimental condition. In the control condition, participants watched a 25-min documentary (Fothergill et al., 2007). Following this procedure in each condition, the athletes performed the respective performance task (see below). The recovery period between the two conditions was at least 48 h.

At each measurement timepoint, participants completed a screening questionnaire to assess several factors which could potentially affect performance. Participants were asked if they had consumed caffeine or food within the last 2 h before testing and alcohol, nicotine or other performance-enhancing substances in the past 12 h. Moreover, in Study 1, participants were asked whether they had engaged in strenuous leg training within the previous 48 h.[1]

2.3. Stress manipulation

Psychosocial stress was induced by the TSST (Kirschbaum et al., 1993). Participants were informed that they would be participating in a simulated job interview and were given 5 min to prepare themselves for the interview in a separate room. Afterwards, participants entered a second room and were asked to give a 5-min unrehearsed speech in front of a 2-person panel, followed by a 5-min arithmetic task (total TSST time: 15 min). Participants were instructed to imagine a situation in the near future after finishing their university studies, in which they were looking for a job and were offered an interview for their dream job. The members of the job committee were introduced as the manager of the respective company and an assistant who is specialized in the interpretation of body language and voice frequency. Throughout the speech, the committee showed neutral facial expressions and only used standardized responses (e.g., “You still have time left. Please continue.”). Furthermore, the social assessment was reinforced by fictitious audio and video recordings as well as additional negative feedback. Subsequently, participants were asked to perform a 5-min arithmetic task by subtracting 13 from a starting number of 1022. If mistakes were made, participants were instructed to start from the beginning. The TSST is an established, and validated procedure that has been successfully used in numerous studies to induce stress (for a comprehensive overview, see Mücke et al., 2018).

2.4. Measures

A detailed presentation of the internal consistencies of all scales used in the studies can be found in Table S1 as an electronic supplement.

[1] If any exclusion criteria were met, exploratory analyses determined if excluding these participants significantly affected the results. This was not the case for any of the three studies.

Stress parameters. Stress was measured in both conditions at baseline (pre) and before performing the respective athletic or cognitive performance task (post) as a manipulation check. In line with Mücke et al. (2020), stress reactivity was calculated by subtracting the post scores for each stress parameter from the pre scores of the respective parameters.

Salivary cortisol samples and heart rate were assessed as *physiological stress parameters*. Cortisol collected from saliva samples represents the stress reactivity of the hypothalamic-pituitary-adrenal axis (Kudielka et al., 2004), the main physiological stress regulation system. Salivary cortisol levels rise with about 10 min delay relative to the stressor onset (Allen et al., 2014). In both conditions, saliva samples were taken at baseline and after watching the documentary (i.e., 10 min after the TSST in the experimental condition) with cortisol salivettes (Salivette® Blue cap, Sarstedt, Nümbrecht, Germany), stored at −20 °C after data assessment and then sent to the Biochemical Laboratory of the University of Trier, Germany, where time-resolved fluorescence immunoassay was applied to analyze cortisol concentrations (in nmol/l). As a parameter indicating the activation of the sympathetic nervous system in reaction to stress, heart rate was monitored before and directly after the TSST. There is evidence that stress exposure increases heart rate as a cardiovascular response (Allen et al., 2014).

Stress exposure can lead to different subjective effects depending upon appraisal of the stressor, yet stress is typically perceived as a subjectively negative experience. As shown in prior research, the TSST typically increases self-reported stress, and anxiety, and decreases calmness (Allen et al., 2014). Consequently, self-reported state anxiety and mood states were assessed before and directly after the stressor as *psychological stress parameters*. The one-dimensional German short scale of the State-Trait Anxiety Inventory (STAI-SKD; Englert et al., 2011) was used to measure the level of state anxiety. Each of the five items (e.g., “I am nervous”) was answered on a 4-point Likert scale ranging from 1 (*not at all*) to 4 (*very*). Mean values were calculated, with higher scores indicating higher levels of state anxiety. Internal consistency was good in all three studies. Furthermore, mood states were assessed with the German short version of the Multidimensional Mood State Questionnaire (MDBF short version A; Steyer et al., 1997). This instrument consists of 12 items and assesses the following three mood dimensions: pleasant–unpleasant (PU; e.g., “satisfied”), awake–sleepy (AS; e.g., “rested”), and calm–restless (CR; e.g., “relaxed”). Each item was answered on a 5-point Likert scale, ranging from 1 (*not at all*) to 5 (*very*). After recoding inverted items, sum scores were calculated for each dimension. Each dimension ranges from 4 to 20, with higher scores indicating better current mood. Internal consistencies were satisfactory throughout all studies (see Supplement 1).

Mental toughness. The German version (VS-MTQ-G; Dziuba et al., 2025) of the Very Short Mental Toughness Questionnaire (VS-MTQ; Kawabata et al., 2021) was used to assess MT. The VS-MTQ-G is a one-dimensional scale consisting of six items (e.g., “Challenges usually bring out the best in me”), with each item being answered on a 5-point Likert scale ranging from 1 (*strongly disagree*) to 5 (*strongly agree*). Participants were advised to respond thoughtfully, considering their regular tendencies, to emphasize the trait-like nature of MT. Mean values were calculated, with higher values indicating higher levels of MT. The internal consistencies of the VS-MTQ-G were just below the recommended threshold in each of the three studies (see Supplement 1).

Coping strategies. Coping strategies were assessed with the German version (Knoll et al., 2005) of the Brief Coping Orientation to Problems Experienced Inventory (Brief COPE; Carver, 1997). A dispositional version of the instruction of the Brief COPE was provided. Participants were asked to think of their usual thoughts and actions while faced with a difficult situation. This questionnaire comprises a total of 28 items answered on 4-point Likert scales ranging from 1 *(I haven't been doing this at all*) to 4 (*I've been doing this a lot*). The Brief COPE has three higher-order coping dimensions according to Dias et al. (2012): PFC (e.g., “I've been taking action to try to make the situation better”), EFC (e.

g., "I've been getting emotional support from others") and AC (e.g., "I've been using alcohol or other drugs to make myself feel better"). Mean values were calculated for all three subscales, with higher values indicating a more frequent use of the respective coping strategy. The PFC and EFC subscales demonstrated acceptable internal consistency in Study 1 and 3, whereas ω did not reach the satisfactory threshold for both subscales in Study 2 (see Supplement 1). Due to inacceptable internal consistencies of the AC subscale in Studies 1 and 3, it was excluded from subsequent analyses.

2.5. Performance tasks

2.5.1. Study 1. Endurance performance on the cycle ergometer

At T1, participants performed an incremental lactate step test to determine the required individual resistance level for the endurance task. Prior to the incremental test, the proper position on the cycle ergometer was adjusted for each subject, and the settings were recorded and reset at the subsequent visits. Following a 3-min warm-up period at no resistance, the incremental test (initial load at 80 W + 25 W increments every 3 min) was performed until exhaustion (defined as a cadence below 60 revolutions per minute (RPM) for more than 5 s despite strong verbal encouragement) on a cycle ergometer (SRM ergometer; for a similar procedure, see also Pageaux et al., 2015). At the beginning of the step test and at the end of each step (i.e., every 3 min), lactate levels were measured via capillary blood sampling from the earlobe and the heart rates were recorded. Samples were collected via test capillaries by supervisors who had been trained by experts from the collaborating performance diagnostic laboratory. Subsequent to the data assessment, the test capillaries were analyzed by iQ athletik GmbH, Germany, using the software Ergonizer (Röcker, 1991-2023). The analyses comprised the determination of the individual anaerobic threshold utilizing the Dmax method (for further details on this approach, see Cheng et al., 1992) and the calculation of the maximum oxygen consumption (relative VO_2max).[2] Before performing the lactate step test, participants' health status was assessed by the German version of the Physical Activity Readiness Questionnaire for Everyone (PAR-Q+; Warburton et al., 2011). The German Society for Sports Medicine and Prevention (DGSP) recommends this health check as an initial screening for sports participants. Participants reporting any of the seven symptoms described in the PAR-Q+ (e.g., "Has a doctor ever told you that you have 'something wrong with your heart' and only recommended exercise and sport under medical supervision?") were excluded.

At T2 and T3, following a 3-min warm-up period on the ergometer with no resistance, subjects cycled at their individual anaerobic threshold until termination (i.e., as soon as the cadence fell below 60 RPM for 5 s). Cadence was freely chosen between 60 and 80 RPM. Participants were neither externally motivated nor given any feedback on elapsed time, power output, and heart rate by the experimenter. The performance criterion was the time until termination (in minutes).

2.5.2. Study 2. Cognitive performance

As previously mentioned, in Study 2, participants were tested twice. At both measurement timepoints, cognitive performance was measured with the d2–R (Brickenkamp et al., 2010). The d2–R is the revised version of the d2 Test of Attention (Brickenkamp & Zillmer, 1998) and is a standardized paper and pencil task designed to assess individuals' general attention regulation ability by asking them to discern target stimuli from distractor stimuli with high visual similarity under time pressure. It measures the respondents' ability to concentrate (adjusted correct responses) as well as their processing speed (total symbols processed) and accuracy (error rates), with which similar visual stimuli can be distinguished. The test consists of a single form with 798 items arranged in 14 rows (rows 1 and 14 are not analyzed), each containing 57 randomly mixed characters, which include the letters "d" or "p" accompanied by one to four dashes above or below. Among the 13 possible characters, the target stimulus is the letter "d" with exactly two dashes, while the remaining characters act as distractors. Participants are instructed to identify and cross out these target stimuli within 20 s per row, moving from left to right and immediately preceding to the next row upon the administrator's cue (i.e., "next line"). When the participants crossed out the incorrect objects, they were permitted to cross them out again immediately (making an X mark). The test is completed without breaks, lasting approximately 5 min.

Key performance metrics derived from the d2–R include: (i) processed target objects (PTO), representing the total number of targets correctly identified; (ii) error percentage (E%), calculated as the ratio of errors (i.e., missed targets and distractors mistakenly crossed out) in relation to the total number of targets processed; (iii) concentration performance (CP), defined as the number of correctly identified targets minus commission errors and omitted targets.

2.5.3. Study 3. Isometric endurance performance of handgrip strength

At T1, to standardize the handgrip task across participants, the individual maximum voluntary contraction (100 % MVC) of the dominant hand was determined. Two 4-s all-out maximum handgrip squeezes separated by 1 min of rest were measured using a handgrip dynamometer (model MLT003/D; ADInstruments) with a digital PC interface (PowerLab ML870; ADInstruments). The average force recording obtained from a 1-s window at the peak of each MVC trial was analyzed to determine peak force generation, and the greater force was halved to determine the 50 % MVC target value for the endurance trials. This isolation task involves isometric muscle contraction with visual feedback, which requires constant fine adjustment of the force in order to avoid excessive force development (Giboin et al., 2019). Isometric handgrip endurance tasks have been used in several studies examining the effects of cognitive control exertion on physical performance (e.g., Bray et al., 2011; Brown & Bray, 2017; Graham et al., 2018).

At T2 and T3, before the handgrip task started, the experimenter set up the force feedback monitor and provided a 10-s demonstration of the isometric endurance handgrip task. For the isometric endurance trials, participants squeezed the handgrip dynamometer with their dominant hand and were provided instantaneous feedback on a computer monitor showing a tracing of their force generation. A static line was displayed to indicate the target force level (50 % MVC). Participants were instructed to maintain the handgrip squeeze for as long as possible, keeping their force tracing line at, or slightly above, the target level, and were given corrective feedback when the force dropped below the target level. When the force fell below the 50 % MVC threshold for longer than 2 s, the test was terminated. Handgrip performance was defined as the total duration participants maintained the isometric endurance handgrip contraction at 50 % of their MVC (in seconds).

Control variables. Changes in performance might stem from alterations in perceived fatigue and motivation (e.g., Inzlicht et al., 2014; Inzlicht & Schmeichel, 2016). It was therefore necessary to ensure that potential differences in performance were not caused by these parameters. To address these potential confounding factors, two additional measurements were taken prior to each endurance test to assess participants' level of motivation at T2 and T3 (for this approach, see Graham & Bray, 2015). To measure *intrinsic motivation*, the German translation (Stocker et al., 2020) of the "Effort and Importance"-subscale from the Intrinsic Motivation Inventory (IMI; Ryan, 1982) was used. Each of the five items was prefaced with the following stem "For the handgrip squeezing task I am going to ...." All items (e.g., "... put a lot of effort into this") were rated on a 7-point Likert scale ranging from 1 (*not at all true*) to 7 (*very true*). Internal consistencies were acceptable in both conditions. To assess *task motivation* prior to each handgrip trial, the

[2] Ergonizer employs gender-specific formulae to estimate the VO_2max, with the relevant parameters of body weight and age being given full consideration. The equations employed in this process are in accordance with the guidelines stipulated by the American Thoracic Society.

single-item Task Motivation Scale (TMS; Hutchinson et al., 2011) was used. Participants were asked to rate their level of motivation to persist with the upcoming task and the effort one intends to exert, using an 11-point Likert-type scale ranging from 0 (*not at all motivated*) to 10 (*extremely motivated*). Finally, at T2 and T3 participants were instructed to report their *perception of effort* (RPE), that is, how heavy or strenuous the exercise felt to them based on the strain and fatigue in their muscles, by answering Borg's (1998) CR10 scale. Participants filled out the CR10 on a scale ranging from 0 (*no exertion at all*) to 10 (*maximal exertion*) following each isometric handgrip endurance trial.

2.6. Statistical analyses

All analyses were conducted using jamovi version 2.3.21.0 with significance testing performed at an α-level of .05. We checked internal consistencies using McDonald's ω, with a threshold of ≥ .70 being considered sufficient (Dunn et al., 2014).

Participants were excluded from the analyses if they did not meet the TSST response criterion of at least a 15.5 % increase in cortisol levels from baseline to post-stress, as proposed by Miller et al. (2013).[3] For each study, bivariate Pearson correlations were calculated between all study variables (i.e., MT, stress parameters, coping strategies, performance criteria, and control variables).

In each study, preliminary analyses were conducted to assess the effectiveness of the respective stress induction by examining the previously mentioned manipulation check variables (i.e., salivary cortisol, heart rate, state anxiety, and mood-state). If these variables were normally distributed, we applied a one-sided paired *t*-test for the experimental condition and a two-sided paired *t*-test for the control condition. In cases of non-normal distribution, a Wilcoxon signed-rank test was employed. Additionally, we assessed potential order effects by performing a 2 (order) x 2 (condition) mixed-design ANOVA, evaluating whether the order of conditions influenced the outcomes. To confirm the uniformity of task load for the individual anerobic threshold (Study 1) and the 50 % MVC (Study 3), we examined the main effects of VO_2max or 100 % MVC on performance using repeated measures ANCOVAs, with condition (experimental vs. control) as the within-subject factor, the relevant performance criterion (i.e., time spent on the task) as the dependent variable, and VO_2max and 100 % MVC as covariates. Within Study 3, possible differences in the control factors (i.e., IMI, TMS, and RPE) between the two conditions were tested using a 2 (order) x 2 (condition) mixed-design ANOVA. To test our main hypotheses, we also performed repeated measures ANCOVAs, with condition (experimental vs. control) as the within-subject factor, the relevant performance criterion as the dependent variable, and MT as a covariate. For exploratory analyses on the potential effects of different coping strategies on performance, we included the three specific coping dimensions (i.e., PFC and EFC) as covariates in this model.

To determine the required sample sizes for each of the three studies, a priori power analyses were performed using G*Power 3.1 (Faul et al., 2009). Given the within-subjects experimental design, repeated measures ANOVA were chosen as the primary statistical tests. This choice was based on the stability of the covariate (i.e., MT or coping strategies), which does not vary across repeated measurements and therefore does not contribute additional variance. We specified an effect size *f* of .386, reflecting a moderate correlation (r = .36) between MT and athletic performance as reported in Hsieh et al.'s (2023) meta-analysis, which led to a required sample size of 20 participants per study (parameters: α = .05, power = .90, r = .50 between repeated measurements). To account for possible exclusions or non-responses in the TSST, the target sample sizes were set at 30 participants per study.

In Study 3, anomalies in the d2-R test results were addressed by examining errors and omissions in the test protocol. Standardized age-appropriate norm values for PTO, E%, and CP (Brickenkamp et al., 2010) were applied, with any test results outside the normal range classified as outliers and excluded from analysis. Complete case analysis was also employed to exclude any participants with missing data across key variables. This was not the case for either analysis.

3. Results

3.1. Sample characteristics

In terms of age, sports experience and type of sport, very heterogeneous groups were reached in each study. The most prevalent types of sports among the recruited participants were weight training, soccer, athletics and parkour. Detailed information on the demographics of the participants is shown in Table 1.

3.2. Preliminary analyses of all three studies

In addition to the stress manipulation check, in each study, we analyzed potential order effects and the influence of the baseline value on each performance parameter (see Supplement 2 for comprehensive results of the preliminary analyses).

Regarding the stress manipulation check, the results revealed a significant increase in cortisol, heart rate and anxiety before and after the stress induction in all three studies in the stress condition. In line with the hypothesis, the PU and CR subscales of the mood-state questionnaire demonstrated a significant decrease. There were no significant changes within the AS subscale in any of the three studies. Across all three studies, a significant decrease was observed for cortisol and state anxiety in the control condition, but not for heart rate. Regarding mood states, there was a significant increase in the CR and PU subscales (only observed in Study 2). Taken together, the present pattern of results indicates that the stress manipulation was effective at group level in each study. Additionally, correlational analyses (see Supplement 3) showed no significant correlations between stress parameters and MT in the stress condition.

The analyses of potential order effects for the specific performance outcomes revealed neither significant interaction effects (order x condition) in Study 1 for the endurance performance, F (1, 25) = .72, p = .405, η_p^2 = .028, nor in Study 3 for handgrip strength, F (1, 26) = 2.33, p = .139, η_p^2 = .082. However, a significant order effect was identified within the cognitive task in Study 2. This was the case for all three

Table 1
Demographics of the final samples, separately for each study.

	Study 1	Study 2	Study 3
Final *N*	27	27	28
TSST non-responders[a] (*n*, %)	5 (15.2)	7 (20.6)	8 (22.2)
Female (*n*, %)	4 (14.8)	10 (37.0)	8 (28.6)[b]
Age (*M*, *SD*)	23.50 (3.48)	23.80 (2.72)	25.40 (5.27)
Sport experience in years (*M*, *SD*)	6.25 (4.69)	13.10 (5.73)	8.21 (7.19)
Competing[c] (*n*, %)	6 (22.2)	13 (50.0)	5 (19.2)
Right-handed (*n*, %)	–	24 (88.9)	27 (96.4)
Mental toughness (*M*, *SD*)	4.00 (.43)	3.94 (.47)	4.04 (.43)

Note.
[a] An increase in cortisol level of 15.5 % compared to the baseline value was defined as the cut-off point (Miller et al., 2013). TSST non-responders were not included in the final *N*.
[b] In this study, one participant self-identified as diverse.
[c] Participants were asked if they currently compete in their main sport.

[3] Dickerson and Kemeny (2004) postulated that cortisol levels typically reach their peak between 21 and 40 min post-stress onset. As our post-stress measurement occurred after 10 min, TSST non-responders were included in subsequent exploratory analyses to determine whether the results were markedly different when including them. However, as these exploratory analyses did not reveal significant changes in the pattern of results in any of the three studies, these results are not further reported.

performance parameters (CP: $F(1, 25) = 98.73, p < .001, \eta_p^2 = .798$; E%: $F(1, 25) = 46.85, p < .001, \eta_p^2 = .368$; and PTO: $F(1, 25) = 76.72, p < .001, \eta_p^2 = .754$), indicating that participants automatically performed better at T2 than at T1 regardless of the order.

The analyses of a potential influence of the baseline value on the respective performance outcome demonstrated a significant main effect of the relative VO_2max on performance within Study 1, $F(1, 25) = 13.2, p = .001, \eta_p^2 = .345$. This finding indicates that participants with higher VO_2max tended to demonstrate better performance. In contrast, influence of 100 % MVC within Study 3 was not statistically significant, $F(1, 26) = 1.28, p = .268, \eta_p^2 = .047$.

Regarding the influence of control factors within Study 3, no significant difference was found between both condition for TMS, $F(1, 26) = 1.38, p = .251, \eta_p^2 = .050$, and RPE, $F(1, 25) = .13, p = .722, \eta_p^2 = .005$, whereas IMI was significantly lower in the stress condition ($M = 5.69$; $SD = 1.08$) than in the control condition ($M = 6.04$; $SD = .95$), $F(1, 26) = 4.28, p = .050, \eta_p^2 = .141$. However, there was no significant interaction effect for all three factors.

3.3. Main analyses on the interaction of MT and stress on performance

Contrary to our hypothesis, the main analyses investigating the association between MT and stress on performance revealed no significant interaction effects, neither for endurance on the bicycle ergometer nor for attention or handgrip strength (see Table 2). The results indicate that MT had no significant effect on performance under stress and that participants performed similarly in both conditions. Further details on the main effects can be found in Supplement 4.

3.4. Exploratory analyses on the different coping strategies

Across each study, the results indicate that PFC is used significantly more often than EFC. Moreover, no significant interaction effect of the individual coping strategies on the different performance results within the three studies could be demonstrated. This suggests that the specific coping strategies were not significantly associated with performance. The detailed results of the exploratory analyses can be found in Supplement 5.

Furthermore, correlation analyses (see Supplement 3) revealed significant relationships between MT and PFC (Study 1: $r = .52$; Study 3: $r = .40$), as well as between PFC and EFC (Study 1 and 3: $r = .51$).

Table 2
Interaction of MT and stress on performance.

Study	Performance outcome		Stress condition *M* (*SD*)	Control condition *M* (*SD*)	Interaction effect
1	Endurance (min)		45.10 (4.13)	41.50 (3.60)	$F(1, 25) = 1.83, p = .188, \eta_p^2 = .068$
2	Attention	CP	209 (37.60)	209 (30.90)	$F(1, 25) = .18, p = .677, \eta_p^2 = .007$
		E%	4.64 (3.90)	4.84 (3.61)	$F(1, 25) = 1.17, p = .289, \eta_p^2 = .045$
		PTO	219 (36.30)	220 (30.80)	$F(1, 25) = .30, p = .864, \eta_p^2 = .001$
3	Handgrip (sec)		58.2 (24.70)	46.2 (23.10)	$F(1, 26) = .63, p = .435, \eta_p^2 = .024$

Note. CP = concentration performance; E% = error percentage; PTO = processed target objects.

4. Discussion

The main purpose of this study series was to examine the influence of MT on the stress-performance relationship. With the current study series, we addressed the lack of research on the acute effects of MT on performance under stress by investigating the influence of MT after a stress manipulation on athletic performance (Study 1: Endurance performance on a cycle ergometer; Study 3: Isometric handgrip endurance strength) as well as on cognitive performance (Study 2: Attention performance within the d2-R Test). Our findings provide important insights into the potential effects of MT and coping strategies on performance under stress. The results indicate that there were no significant interactions between MT and stress on performance in any of the three studies. Furthermore, athletes seem to use PFC strategies more often than EFC strategies. Nevertheless, the use of the respective coping strategies was not significantly associated with performance in any of our studies.

4.1. Association between MT, stress and performance

Our results did not support the hypotheses that participants with lower levels of MT would perform worse under stress (experimental condition) compared to no stress (control condition), whereas athletes with higher levels of MT would perform similarly across both conditions. In contrast to our expectations, the main analyses revealed no significant interaction effect of MT and stress on performance, suggesting that MT did not have a significant impact on performance.

This observation contradicts previous findings, which indicate that athletes with higher MT are more adept at managing stress (Gucciardi et al., 2015) and use it to enhance their performance (Jones et al., 2007; Weinberg, 2010). Professional athletes frequently encounter challenging and stressful situations, with MT being recognized as a crucial factor for overcoming both physical (e.g., fatigue) and mental (e.g., stress, pressure) demands (Connaughton et al., 2008; Cowden et al., 2020). Crust and Clough (2005) identified a positive correlation between MT and physical endurance performance in a weight-hold task, attributing this relationship to the ability of mentally tough individuals to block out sensations of pain and tolerate discomfort for longer periods of time (for similar findings, see also Jones et al., 2002; Levy et al., 2006). Our contrary findings might be explained by the laboratory settings of our studies. In such a hypothetical scenario, MT may not be effective because it does not align with the demands of a realistic competitive environment. In competitive settings, athletes strive to outperform and defeat their opponents. In the context of laboratory settings, the potential outcomes of victory or defeat are absent (for a critical discussion, see also Mesagno et al., 2015). The absence of this primary motivator could result in a reduction in the athletes' drive to perform at their best. Furthermore, the participants may not have perceived the performance task as threatening, potentially resulting in boredom or diminished motivation to endure prolonged pain. Both factors could exert a negative influence on performance (e.g. Wolff et al., 2024). Future research should examine the relationship between MT and performance in actual competitive settings. This has practical significance because athletes frequently face stressful conditions (e.g., competitions, audience, technical mistakes), in which their mindset may make the difference between winning or losing against their opponents. Understanding the mechanisms through which MT influences athletic as well as cognitive performance under stress could lead to the development of more effective training and psychological support strategies for athletes. Enhancing MT (for a systematic review and meta-analysis, see Stamatis et al., 2020) might not only improve individual athletic performance but also contribute to overall team success in competitive sports.

Additionally, our results showed no significant difference in any of the three performance outcomes between both conditions across all three studies. The experimental condition potentially induced a more pronounced sense of activation among the athletes compared to the control condition, which subsequently influenced their performance positively and offset any potential influence of MT. In general, stress tends to have a negative effect on performance, but a certain level of stress might also lead to an activation of the body (Strahler & Lautenbach, 2024). Hanin (2000) indicates in his model of Individual Zones of Optimal Functioning (IZOF) that stress is not inherently beneficial or harmful, as significant inter-individual differences exist in how it affects performance. Unlike models focusing on an optimal activation point, Hanin's approach is based on the concept of individualized zones, proposing that while certain emotions may enhance performance for some athletes, they may negatively impact others. These assumptions have been extensively supported by empirical studies (e.g., Ruiz et al., 2017). It is reasonable to assume that participants have a middle IZOF due to their high level of MT and that the higher stress in the experimental condition therefore led more to an activation rather than impairment. Conversely, the control condition may have led to a greater degree of relaxation, potentially resulting in impaired performance. It should be noted that, on a descriptive level, the stress parameter AS (i.e., awake-sleepy) revealed a decrease in activation across almost all conditions. However, these differences did not reach statistical significance.

4.2. Association between MT and coping

Exploratory analyses showed that, in general, participants use PFC strategies more often than EFC strategies. Furthermore, MT was positively associated with PFC in Studies 1 and 3 (see Supplement 3).

These findings are consistent with previous research demonstrating that mentally tough athletes are more likely to employ PFC strategies while relying less on AC strategies (Dias et al., 2012; Kaiseler et al., 2009; Nicholls et al., 2008), indicating a tendency to proactively deal with stressors. However, the present study did not support previous findings and the a priori hypothesis that coping strategies (i.e., PFC) would be associated with better performance. Poulus et al. (2020) postulated that athletes with lower levels of MT who rely on AC strategies may be less skillful and may not perform as well as athletes with higher levels of MT.

Additionally, correlational analyses (see Supplement 3) showed inconclusive results regarding the stress appraisal process. The non-significant association between MT and stress parameters in the stress condition suggests that participants with both high and low MT experienced similar levels of stress during the TSST. These results are contrary to previous research on MT, in which various studies indicated that MT profoundly influences stress appraisals by promoting a challenge-oriented perspective (Levy et al., 2012; Nicholls et al., 2012), fostering a sense of control (Poulus et al., 2020), reducing perceived stress intensity (Gerber et al., 2013; Kaiseler et al., 2009), and enabling athletes to cope more effectively (Nicholls & Polman, 2007). According to Clough et al. (2002), mentally tough individuals are characterized by their strong tendency to view their environment as controllable, to perceive themselves as confident, to stay committed during adversity, and to view challenges as opportunities for growth. This concept may explain why they usually perceive less stress or have higher stress tolerance levels. With a few exceptions (i.e., relationship PFC-CR in Study 1 and 3; and relationship PFC-anxiety in Study 3), no significant correlations were found between coping strategies and stress parameters in the stress condition. Relatively few studies have explored coping effectiveness (i.e., degree in which a coping strategy is successful in alleviating stress) in sport. Polman (2011) postulated that the coping strategies most frequently employed by athletes are not always the most effective. According to Eubank and Collins' (2000) choice of coping strategy hypothesis, the effectiveness of a coping strategy depends on the type of strategy used, indicating that some strategies are more effective than others. In this context, EFC strategies should not be underestimated, as they play a crucial role in down-regulating intense emotional states, enabling athletes to utilize PFC strategies more effectively to address the stressor (Polman, 2011). The results in the present study might be explained by the fact of using the dispositional version of the Brief COPE (Carver, 1997), which asks about the habitual thoughts and actions of participants when confronted with challenging circumstances. These strategies are not context sensitive. Therefore, it is possible that participants were unable to use their usual coping strategies in the specific laboratory setting, either within the TSST or within the performance task. Given that the performance task might not have been perceived as a potential threat, there was no need for applying a certain coping strategy. Future research should take a more holistic approach by examining appraisal of stressful events (i.e., as challenge or threat), the associated emotions (negative or positive), the coping strategies employed, their effectiveness, and the resulting performance outcomes.

5. Limitations and future research direction

The present study series is not without limitations. A limiting factor that should be taken into account is the significant order effect for all three cognitive performance parameters (i.e., CP, E%, and PTO) within Study 2, indicating that there is a learning effect between T1 and T2. Practice-related effects through test repetition are by no means specific to the d2-R Test, as comparable effects have also been observed for other concentration tests (e.g., Bühner et al., 2006). In their manual on the d2-R Test, Brickenkamp et al. (2010) postulated a negligible practice effect for the d2-R with a test duration of ten days. However, several studies have also shown that d2 performance increases significantly with practice (e.g., Westhoff, 1989). Wühr (2019) has proposed a solution to this issue in the form of using two different non-overlapping versions of the test (e.g., alternating targets) for repeated measures. However, the d2 (Brickenkamp & Zillmer, 1998) and the revised version d2-R (Brickenkamp et al., 2010) are widely utilized paper-pencil tests of attention, as they are simple, objective and reliable instruments (e.g., Wühr, 2019). Due to the cross-over design with balanced groups, this practice-related effect is negligible. Another limiting factor is the significant influence of baseline value on performance in Study 1, implying that participants with higher VO_2max automatically performed better in the endurance task on the cycle ergometer. This should be considered when interpreting the results. Despite individualization of the exercise load the influence of MT on performance across both conditions cannot be considered in isolation. This effect is often observed in amateur sport, largely attributable to the considerable differences in the physical constitutions of the athletes. Conversely, in elite sports, the outcome of a competition oftentimes is primarily driven by psychological factors (Brewer, 2009). In Study 3, the significant main effect for IMI indicates that participants in the control condition were slightly more intrinsically motivated to perform well in the handgrip endurance task compared to the stress condition. Although the differences were small, they can still influence performance. Finally, it should be noted that the variance in MT was low across all three studies. The samples consisted mostly of athletes with high levels of MT, which could potentially explain the absence of substantial findings concerning the influence of MT. It has been noted that other studies encountered similar challenges of high average MT in their samples (e.g., Brace et al., 2020; Mahoney et al., 2014) and a low variance when using different MT questionnaires (e.g., Crust & Clough, 2005; Gerber et al., 2013; Kaiseler et al., 2009; Levy et al., 2012)

6. Conclusion

The present study series provides no empirical support that MT or certain coping strategies moderate the stress-performance relationship. The results indicate that athletes tend to use PFC strategies more often than EFC strategies, and that the use of PFC is associated with the individual level of MT. Further research is required to investigate the influence of MT on the stress-performance relationship in more applied experimental settings and to gain insights into its influence on the coping process.

CRediT authorship contribution statement

Anna Dziuba: Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Fabienne Ennigkeit:** Writing – review & editing, Supervision, Methodology, Formal analysis, Conceptualization. **Markus Gerber:** Writing – review & editing, Supervision, Methodology, Formal analysis, Conceptualization. **Sebastian Mühlenhoff:** Writing – review & editing, Formal analysis, Conceptualization. **Chris Englert:** Writing – review & editing, Supervision, Methodology, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.psychsport.2025.102938.

Data availability

Data will be made available on request.

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