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# Trained men show lower cortisol, heart rate and psychological responses to psychosocial stress compared with untrained men

Ulrike Rimmele<sup>a</sup>, Bea Costa Zellweger<sup>b</sup>, Bernard Marti<sup>c</sup>, Roland Seiler<sup>d</sup>, Changiz Mohiyeddini<sup>e</sup>, Ulrike Ehler<sup>b</sup>, Markus Heinrichs<sup>a,\*</sup>

<sup>a</sup>Department of Psychology, Clinical Psychology and Psychobiology, University of Zürich, Binzmühlestrasse 14/Box 8, CH-8050 Zürich, Switzerland

<sup>b</sup>Department of Psychology, Clinical Psychology and Psychotherapy, University of Zürich, Binzmühlestrasse 14/Box 26, CH-8050 Zürich, Switzerland

<sup>c</sup>Swiss Federal Office of Sports, CH-2532 Magglingen, Switzerland

<sup>d</sup>Institute of Sport Science, University of Berne, Bremgartenstrasse 145, CH-3012 Berne, Switzerland

<sup>e</sup>Whitelands College, Roehampton University, Holybourne Avenue, London SW15 4JD, UK

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## Summary

Physical activity has proven benefits for physical and psychological well-being and is associated with reduced responsiveness to physical stress. However, it is not clear to what extent physical activity also modulates the responsiveness to psychosocial stress. The purpose of this study was to evaluate whether the reduced responsiveness to physical stressors that has been observed in trained men can be generalized to the modulation of physiological and psychological responses to a psychosocial stressor. Twenty-two trained men (elite sportsmen) and 22 healthy untrained men were exposed to a standardized psychosocial laboratory stressor (Trier Social Stress Test). Adrenocortical (salivary free cortisol levels), autonomic (heart rate), and psychological responses (mood, calmness, anxiety) were repeatedly measured before and after stress exposure. In response to the stressor, cortisol levels and heart rate were significantly increased in both groups, without any baseline differences between groups. However, trained men exhibited significantly lower cortisol and heart rate responses to the stressor compared with untrained men. In addition, trained men showed significantly higher calmness and better mood, and a trend toward lower state anxiety during the stress protocol. On the whole, elite sportsmen showed reduced reactivity to the psychosocial stressor, characterized by lower

\*Corresponding author. Tel.: +41 44 635 7363; fax: +41 44 635 7159.

E-mail address: [m.heinrichs@psychologie.uzh.ch](mailto:m.heinrichs@psychologie.uzh.ch) (M. Heinrichs).

adrenocortical, autonomic, and psychological stress responses. These results suggest that physical activity may provide a protective effect against stress-related disorders.

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## 1. Introduction

There is substantial evidence indicating that physical activity has beneficial effects on physical and mental health and that it is protective against the detrimental consequences of chronic stress and stress-related diseases, such as cardiovascular disorders (Perkins et al., 1986; Steptoe et al., 1993; Talbot et al., 2002; Ketelhut et al., 2004; Barlow et al., 2006) or depression (Ross and Hayes, 1988; Blumenthal et al., 1999; Babyak et al., 2000; Motl et al., 2004; Nabkasorn et al., 2006). In addition, several studies demonstrated that regular physical activity contributes to a reduced responsiveness to acute physical stressors (Luger et al., 1987; Deuster et al., 1989; Petruzzello et al., 1997) or reported reduced susceptibility to the adverse influences of life stressors in physically active people (Tucker et al., 1986; Steptoe et al., 1989; Throne et al., 2000). However, the extent to which physical activity may reduce the responsiveness to *psychosocial* stressors, thereby contributing to the prevention of stress-related disorders with major public health significance, is still a much-contested issue (McEwen, 1998).

The physiological reactivity to both physical and psychological stressors leads to increases in cardiovascular and neuroendocrine measures, reflecting autonomic nervous system (ANS) and hypothalamic–pituitary–adrenal (HPA) axis responses (Luger et al., 1987; Deuster et al., 1989; Kirschbaum et al., 1993; Duclos et al., 1997; Singh et al., 1999; Dickerson and Kemeny, 2004). Following chronic stress, alterations in these systems have been linked to the development of stress-related disorders (Steptoe, 1991; McEwen, 1998). Interestingly, physical activity has been found to reduce ANS and HPA reactivity to physical stressors in trained subjects (Luger et al., 1987; Deuster et al., 1989). A possible adaptation of stress-responsive systems due to exercise may influence stress responses not only to physical stressors but also to mental stressors (Clayton, 1991; Cox, 1991; Sothmann et al., 1991, 1996).

Based on this background, physical activity could be regarded as a general protective factor against different kinds of stressors. However, both cross-sectional and longitudinal studies using psychosocial stressors have reported inconsistent findings (de Geus and van Doornen, 1993), with the vast majority of these studies focusing on cardiovascular changes. Whereas some studies reported blunted cardiovascular responses or a more rapid recovery in trained men (Sinyor et al., 1983, 1986; Holmes and Roth, 1985; Crews and Landers, 1987; Boutcher and Landers, 1988; Steptoe et al., 1990; Moya-Albiol et al., 2001; Spalding et al., 2004), others were unable to confirm such effects, or even reported higher reactivity (de Geus and van Doornen, 1993; Jackson and Dishman, 2006). With respect to the sympathetic-adrenal-medullary reactivity, some studies found no effect of fitness on norepinephrine and epinephrine levels in plasma or urine (Brooke and Long, 1987; Clayton

et al., 1988; de Geus et al., 1993), while others reported higher norepinephrine levels in plasma in trained subjects early on in the stress period (Sinyor et al., 1983). In contrast, some studies found lower levels of fitness to be associated with an augmented norepinephrine response (Sothmann et al., 1991; Moyna et al., 1999). Notably, studies on HPA axis reactivity to psychological stressors did not show significant effects of physical fitness on cortisol levels (Sinyor et al., 1983; Moyna et al., 1999). Regarding psychological measures, Sinyor et al. (1983) found aerobically fit subjects to exhibit lower state anxiety following a psychological stressor. It appears that being physically active may differentially influence an individual's reactivity to psychosocial stress depending on the kind and intensity of physical activity, the level of physical fitness, the age and gender of the subjects, the method of measurement, the time of day of stress induction, and the type of stressor. It might be the case that these previous studies (Sinyor et al., 1983; Moyna et al., 1999) used stressors with less social impact, which might have prevented different responses in physically trained versus untrained subjects. In contrast, studies using a stressor that combines mental arithmetic and a speech test induced a strong endocrine response (Biondi and Picardi, 1999), but have barely been used to investigate the stress response of trained men. We used the standardized Trier Social Stress Test (TSST) (Kirschbaum et al., 1993), which enables a naturalistic exposure to a socio-evaluative stressful situation, with two- to three-fold increases in HPA axis and cardiovascular responses (Dickerson and Kemeny, 2004).

In the present study, we set out to determine possible protective effects of a high level of physical activity on parallel measures of adrenocortical (salivary cortisol), autonomic (heart rate), and affective (mood, calmness, anxiety) responses to a standardized psychosocial stressor. To compare stress responses between two groups that clearly differ in their level of physical activity, we included well-trained (elite sportsmen) and untrained men in this study.

## 2. Methods

### 2.1. Participants

Twenty-two elite sportsmen (mean  $\pm$  SD; age,  $21.50 \pm 2.35$  years) and 22 untrained men ( $21.84 \pm 2.24$  years) were recruited by the Swiss Federal Office of Sports and by advertisements at the local universities in Zürich. Elite sportsmen were primarily recruited from endurance-trained sports and had a Swiss Olympic Card and/or were members of the Swiss national teams. Subjects who exercised for less than 2 h per week were classified as “untrained”. Trained and untrained men did not significantly differ in terms of age, BMI, psychological symptoms, and perceived stress (all

**Table 1** Description of the study groups.

	Trained men ( <i>n</i> = 22)	Untrained men ( <i>n</i> = 22)	<i>t</i> -test ( <i>P</i> )
Age (years)	21.50 ± 2.35	21.84 ± 2.24	NS
Body mass index (kg/m <sup>2</sup> )	23.17 ± 1.90	23.28 ± 3.22	NS
Symptom Checklist (SCL-90-R, Global Severity Index)	0.53 ± 0.30	0.62 ± 0.27	NS
Perceived stress (PSS)	20.95 ± 6.96	23.85 ± 5.37	NS
Trait anxiety (STAI)	32.19 ± 7.30	36.45 ± 6.44	.055
Self-efficacy (ICCB)	71.24 ± 8.48	62.90 ± 8.97	.004

Data are expressed as mean ± SD; NS—not significant; PSS—Perceived Stress Scale; STAI—State-Trait Anxiety Inventory; ICCB—Inventory on Competence and Control Beliefs.

$p > .1$ ). Trained men exhibited significantly higher levels of self-efficacy ( $t[39] = 3.06$ ,  $p < .01$ ) and a trend toward lower levels of trait anxiety compared with untrained men ( $t[39] = 1.98$ ,  $p = .055$ ). Characteristics of the sample are shown in Table 1.

Participants were ineligible if they were using medication or reported any mental or medical illness. Further exclusion criteria were smoking more than five cigarettes per day and increased levels of chronic stress (Perceived Stress Scale (PSS; Cohen et al., 1983; see Section 2.4). Three of the original 44 subjects did not meet the eligibility criteria and were excluded: two with acute seasonal allergic rhinitis (one elite sportsman and one untrained man) and one who met criteria for a mental health disorder based on the Symptom Checklist (SCL-90-R) (Derogatis, 1983) (one untrained man). The study was approved by the institutional review board of the University of Zürich. Before entering the study, all participants gave written informed consent and were informed of their right to discontinue participation at any time. After the experiment, subjects were compensated with 50 Swiss francs for their participation.

## 2.2. Procedure

Participants were asked to refrain from eating, drinking anything but water, and intense physical exercise for at least 2 h prior to the experiment. In order to avoid states of overtraining resulting from an imbalance between training stress and recovery, all experimental sessions with elite sportsmen were scheduled following a 10-day recovery phase without a strenuous training schedule. All experimental sessions lasted for 2 h and were conducted between 13:00 and 17:00 h in order to capture maximum cortisol reactivity (Dickerson and Kemeny, 2004). After reporting to the laboratory, all subjects were given a standardized drink of 250 ml of grape juice (Kirschbaum et al., 1997). Psychosocial stress was induced by the TSST (Kirschbaum et al., 1993), comprising a 5-min public speaking task and a subsequent 5-min mental arithmetic task in front of an unknown panel of one man and one woman. After entering the TSST room, subjects remained in a standing position throughout the 10-min stress protocol. The TSST reliably induces two- to three-fold increases in HPA axis and cardiovascular responses (Kirschbaum et al., 1999; Heinrichs et al., 2001, 2003; Dickerson and Kemeny, 2004).

Notably, it has been found to be the socio-evaluative character of the TSST that is crucial for the robust stress response (Dickerson and Kemeny, 2004). In order to ensure high ego involvement, both groups were confronted with subjectively important situations. Elite sportsmen were instructed to apply for a contract with a sponsor and untrained men were asked to convince the audience that they were the most suitable persons for a job of their choice. Under both conditions, the panel of evaluators was presented as experts in evaluating nonverbal behavior. Following completion of the stress session, subjects were instructed to rest quietly for 90 min until saliva sampling was completed.

## 2.3. Endocrine and autonomic measures

Adrenocortical and autonomic responses to the psychosocial stressor were assessed by repeated measures of salivary free cortisol levels and heart rate. Salivary free cortisol has been found to be highly correlated with the unbound cortisol concentration in plasma and is considered to be a reliable and valid indicator of the biologically active fraction of cortisol (Vining et al., 1983; Kirschbaum and Hellhammer, 1989, 1994). Salivary cortisol was collected immediately before (−1 min relative to the onset of the TSST) and after stress exposure (+10, +20, +30, +45, +60, +90 min) using a commercially available sampling device (Salivette; Sarstedt, Rommelsdorf, Germany). After each experimental session, saliva samples were stored at −20 °C. For biochemical analyses of free cortisol concentration, saliva samples were thawed and spun at 3000 rpm for 10 min to obtain 0.5–1.0 ml clear saliva with low viscosity. Salivary cortisol concentrations were determined using a commercially available chemiluminescence immunoassay (CLIA; IBL Hamburg, Germany). Intra and interassay coefficients of variation were 8.4% and 4.6%, respectively.

Heart rate was monitored at 5-s intervals throughout the experiment using a wireless chest heart rate transmitter and a wrist monitor recorder (Polar S810i<sup>TM</sup>, Polar Electro, Finland). For analysis, 1-min intervals were computed from 1 min before stress exposure until 2 min after cessation of the stressor. Baseline measures were assessed in a standing position before subjects entered the TSST room. Heart rate measures of one elite sportsman and two untrained men were partially missing due to technical problems and had to be excluded from the analyses.

## 2.4. Psychological measures

Subjects completed questionnaires designed to measure demographic items, personality characteristics, psychopathological symptoms, self-efficacy, perceived stress, and overtraining (elite sportsmen). Before and after the stressor, mood, calmness, and state anxiety were repeatedly assessed. The validated German versions of the following questionnaires were included: the Symptom Checklist (SCL-90-R) for screening symptoms of psychopathology (Derogatis, 1983), the State-Trait Anxiety Inventory (STAI) for measuring anxiety (Spielberger et al., 1970), the Inventory on Competence and Control Beliefs (ICCB) for assessing self-efficacy (Krampen, 1991), the PSS for measuring perceived stress (Cohen et al., 1983), and the Recovery-Stress Questionnaire for Athletes (RESTQ-Sport) (Kellmann and Kallus, 2001) for assessing possible overtraining. Affective responses before and after stress exposure were repeatedly assessed with the state scale of the STAI (Spielberger et al., 1970) and the Multidimensional Mood Questionnaire (Steyer et al., 1997). All questionnaires have been broadly used and have shown satisfactory internal consistency and validity. The Cronbach's index of internal consistency of the questionnaires are  $\alpha = .98$  for the global severity index of the SCL-90-R, between  $\alpha = .80$  and  $.86$  for the PSS, between  $\alpha = .67$  and  $.89$  for the 19 subtests of the RESTQ-Sport,  $\alpha = .90$  for the trait anxiety scale of the STAI, and between  $\alpha = .73$  and  $.85$  for the self-efficacy subscale of the ICCB. Regarding the state measures, the reliability coefficients were  $\alpha = .90$  for the state scale of the STAI and between  $\alpha = .73$  and  $.89$  for the subscales of the MDBF.

## 2.5. Statistical analysis

Baseline differences between the two groups were examined with *t*-tests for independent samples. To determine changes in cortisol levels, heart rate, state anxiety, mood, and calmness, two-way ANOVAs with repeated measures were calculated with group (trained vs. untrained men) as the between-subject factor and time as the within-subject factor (repeated measures: 2 for state anxiety, mood, and calmness; 7 for cortisol; 14 for heart rate). Where the Mauchly test of sphericity indicated heterogeneity of covariance, we verified repeated-measures results with Greenhouse-Geisser corrections. Homogeneity of variance was assessed using the Levene test. The level of significance was set at  $p < .05$  for two-sided tests. All statistical analyses were performed using SPSS 12 (SPSS Inc., Chicago, IL).

## 3. Results

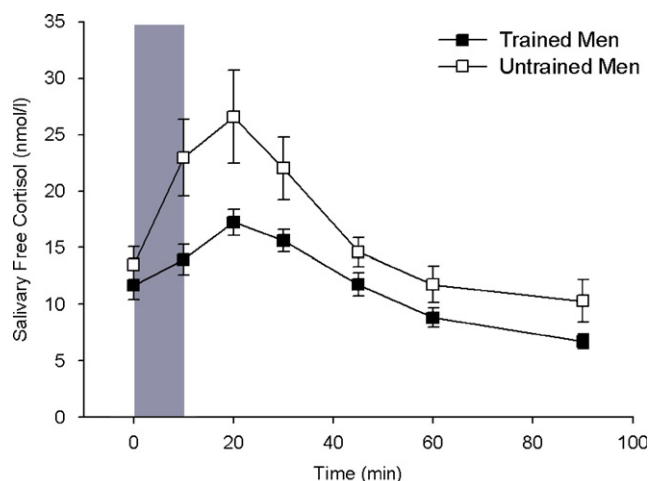
### 3.1. Cortisol responses to stress

Replicating prior research, repeated-measures ANOVA confirmed that the psychosocial stress protocol induced significant increases in salivary free cortisol levels in both groups (main effect of time:  $F[2.72, 106.1] = 31.52, p < .01$ ). Cortisol levels did not differ between groups at baseline ( $t[39] = 0.9, p = .37$ ). However, trained men showed significantly lower cortisol responses to the stressor compared

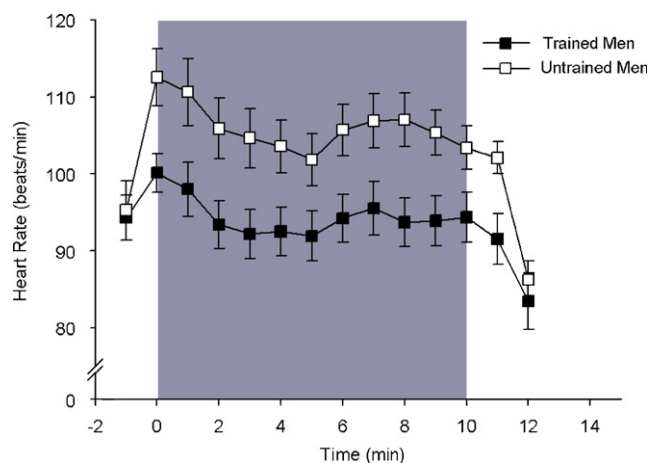
with the group of untrained men, yielding a significant main effect of group ( $F[1, 39] = 5.47, p < .05$ ) and a significant group by time interaction ( $F[2.72, 106.1] = 3.08, p < .05$ ) (Fig. 1).

### 3.2. Heart rate responses to stress

Both groups showed the expected significant increase in heart rate in response to the psychosocial stressor (main effect of time:  $F[5.01, 185.18] = 27.39, p < .01$ ). Again, no significant differences were observed between groups at baseline ( $t[37] = 0.66, p = .51$ ). In response to the stressor, trained men showed significantly lower heart rate reactivity compared with untrained men, yielding a significant main effect of group ( $F[1, 37] = 7.27, p < .05$ ) and a significant group by time interaction ( $F[5.01, 185.18] = 2.53, p < .05$ ) (Fig. 2).



**Figure 1** Mean salivary free cortisol levels before, during, and after a standardized psychosocial stressor (Trier Social Stress Test) in trained and untrained men. The shaded area indicates the 10-min period of stress exposure. Error bars are standard errors of the mean (SEM).



**Figure 2** Mean heart rates before, during (shaded area), and after a standardized psychosocial stressor in trained and untrained men. Error bars are SEM.





**Figure 3** Mean levels (with SEM bars) of mood (A), anxiety (B), and calmness (C) before and after psychosocial stress exposure in trained and untrained men.

### 3.3. Affective responses to stress

The stress protocol significantly worsened mood in both groups (main effect of time:  $F[1, 39] = 4.53, p < .05$ ). Whereas trained and untrained men did not differ at baseline before the stressor ( $t[39] = 1.1, p = .28$ ), there was a significant group by time interaction effect ( $F[1, 39] = 5.80, p < .05$ ), indicating worse mood levels following stress in the untrained group (Fig. 3A).

Following stress exposure, state anxiety significantly increased in both groups ( $F[1, 38] = 6.05, p < .05$ ). Trained men exhibited a trend toward lower levels of state anxiety during the baseline measurement ( $t[38] = 1.9, p = .07$ ). There was a significant main effect of group ( $F[1, 38] = 15.55, p < .001$ ) and a trend toward an interaction effect (group by time:  $F[1, 38] = 3.16, p = .08$ ) on state anxiety, with a marked increase in anxiety levels in response to the stressor in the group of untrained men (Fig. 3B).

There was no significant change in calmness during the stress protocol in the total group of subjects ( $F[1, 39] = 2.47, p = .12$ ). Groups differed significantly at baseline ( $t[39] = 2.15, p < .05$ ). A main effect of group on calmness was observed ( $F[1, 39] = 16.45, p < .01$ ), demonstrating higher calmness levels in trained men compared with untrained men throughout the experimental session (Fig. 3C).

### 3.4. Correlations between affective responses and physiological responses

While mood did not correlate with the physiological stress measures, the differences in pre- to post-stress scores of calmness and state anxiety correlated significantly with the area under the curve (AUC) increase of cortisol (calmness:  $r = .31, p < .05$ ; state anxiety:  $r = -.38, p < .05$ ) in the total group of subjects. The difference in pre- to post-stress scores of calmness correlated significantly with the AUC increase of heart rate ( $r = .33, p < .05$ ). All other correlations between psychometric measures and physiological stress responses were non-significant. There were no significant correlations between psychometric and physiological measures within both groups.

### 3.5. Role of self-efficacy for group differences in stress responses

As physical activity has been shown to provide a mastery experience that leads to increased self-efficacy (McAuley et al., 1995; Netz et al., 2005), and self-efficacy has, in turn, been associated with lower anxiety and lower physiological stress reactivity (Schwarzer, 1992; Bandura, 1997; Butki et al., 2001), higher levels of self-efficacy in elite sportsmen might contribute to a reduced stress reactivity. In order to determine whether group differences between trained and untrained subjects in stress responses may be moderated by self-efficacy, we used a hierarchical regression analysis (Cohen and Cohen, 1975). As dependent variables, indicators of stress reactivity were calculated. In order to include repeated measurements, the trapezoid formula was used to calculate the AUC with reference to the individual baseline level at  $-1$  min for cortisol and heart rate (Pruessner et al., 2003). The  $AUC_i$  is related to the sensitivity of the biological system, characterizing changes over time (Pruessner et al., 2003). For the assessment of psychological changes, change scores between pre- and post-stressor values were calculated for calmness, mood, and state anxiety. Given that self-efficacy is uncorrelated with the dependent variables (all  $r < .30, n.s.$ ) and in order to avoid suppression effects, we first included the variable group in the analysis. In the second step, the variable self-efficacy was included, and finally, the newly composed variable group by self-efficacy (moderation effect) was included. All dependent variables were included in separate analyses.

The results of the hierarchical regression analysis indicate that the relationships between the variable group and all dependent variables (cortisol, heart rate, state anxiety, mood, calmness) were not moderated by self-efficacy (all  $\Delta R^2 < .02$ , all  $\Delta F < 3.5, n.s.$ ).

## 4. Discussion

The health beneficial and stress-protective role of physical activity is a well-known but poorly characterized phenomenon. This is the first study to examine possible protective effects of physical activity on parallel measures of adrenocortical,

autonomic, and psychological responses to a standardized psychosocial stressor in well-trained (elite sportsmen) and untrained healthy men. By including elite sportsmen and untrained men in our study, we circumvented the limitations of self-reported levels of physical activity on a continuum or group assignments based on median split. Stress induction proved to be successful, as indicated by significant increases of cortisol concentrations and heart rate, and by changes in affective measures in the total sample. While groups did not differ at baseline level (−1 min before stress exposure) for the major physiological and psychological variables, the results demonstrated markedly reduced physiological and psychological stress responsiveness in trained compared to untrained subjects. Specifically, the group of trained men showed reduced salivary free cortisol and heart rate responses to the psychosocial stressor. Notably, we observed corresponding results in affective measures, indicating that trained men were generally calmer and exhibited better mood and lower anxiety throughout stress exposure. Moreover, untrained men showed an increase in anxiety and a decrease in mood and calmness during stress, whereas trained men did not. Thus, the present data extends previous research by demonstrating protective effects of a high level of physical activity on both physiological and psychological reactivity to a psychosocial stressor.

To our knowledge, the current study is the first to show markedly lower cortisol responsiveness following psychosocial stress in trained men compared to untrained men. Two previous studies were unable to find significant differences in cortisol responses to a psychological stressor between trained and untrained men (Sinyor et al., 1983; Moyna et al., 1999). A possible explanation for the observed differences might be due to the stress protocols, since the HPA axis is not particularly sensitive to mental arithmetic tasks or Stroop tests (Sinyor et al., 1983), as recently shown by Biondi and Picardi (1999). In contrast, it has been reported that stressors consisting of a combined public speech and cognitive task with an uncontrollable and socio-evaluative character (e.g., TSST) reliably induce a greater cortisol response than other stressors (Dickerson and Kemeny, 2004).

We further found lower heart rate reactivity to the TSST in elite sportsmen in comparison to the group of untrained men, replicating previous findings on reduced heart rate responsiveness to a psychological stressor in trained subjects (Heidbreder et al., 1983; Holmes and Roth, 1985; Brooke and Long, 1987; Crews and Landers, 1987; de Geus et al., 1990; Claytor, 1991; Moya-Albiol et al., 2001; Spalding et al., 2004). In addition, our findings are in line with longitudinal studies, which reported that aerobic training leads to lower cardiovascular reactivity to psychological stressors (Throne et al., 2000; Spalding et al., 2004). Conversely, a recent meta-regression analysis showed physical fitness to be related to slightly higher cardiovascular reactivity to psychological stressors (Jackson and Dishman, 2006). The exclusion of elite sportsmen in the meta-regression analysis may be one (albeit not comprehensive) reason for this contradictory finding. Interestingly, it has been found that elite sportsmen show lower heart rate reactivity to a psychological stressor than amateur sportsmen (Moya-Albiol et al., 2001).

With regard to the psychological stress response, the present data build on previous research by demonstrating affective advantages in trained men compared with un-

trained men. Our findings on stress-related anxiety levels are consistent with the results of previous studies, which reported state anxiety to be lower in trained compared to untrained subjects after cessation of the stressor (Sinyor et al., 1983). As trained men showed lower state anxiety before stress as well as a statistical trend toward lower trait anxiety in our study, it might be speculated that physically trained subjects generally appraise acute psychosocial stressors as less threatening and more controllable than untrained individuals do, which may in turn modulate the activity of the HPA axis and the ANS. For example, longitudinal studies demonstrated a decrease in anxiety following a 12-month or 16-week-long exercise intervention in contrast to control subjects without an exercise intervention (King et al., 1993; Throne et al., 2000). In addition, consistent with our finding of better mood and a significantly higher level of self-efficacy in elite sportsmen, acute and chronic exercise have been shown to improve mood and self-efficacy (McAuley et al., 1995; Butki et al., 2001; Salmon, 2001; Netz et al., 2005). Since physical activity may provide a mastery experience that leads to increased self-efficacy (McAuley et al., 1995; Netz et al., 2005), and self-efficacy has, in turn, been associated with lower anxiety and lower physiological stress reactivity (Schwarzer, 1992; Bandura, 1997; Butki et al., 2001), it may be that the significantly higher level of self-efficacy in elite sportsmen might have contributed to their reduced stress reactivity in the present study. However, the hierarchical regression analysis reported above showed that the higher level of self-efficacy in elite sportsmen did not contribute to the observed lower stress reactivity. Thus, the favorable effect of physical activity on coping with psychosocial stress may be due to physiological or psychological benefits, other than self-efficacy. Future studies should further investigate the relationship between physical activity levels and personality traits or cognitive strategies, which may interact in modulating the responsiveness to psychosocial stress.

The reduced stress reactivity of trained men in our study might be explained by an exercise-induced modulation in stress-responsive hormonal and autonomic nervous systems. Notably, chronic exposure to physical stressors affords redundant activation of the HPA axis and the sympathetic nervous system (Luger et al., 1988; Filaire et al., 2002). Exercise-trained individuals show a reduction in pituitary–adrenocortical activation (Luger et al., 1987; Sothmann et al., 1996) and a lower degree of sympathetic system activation in response to a given absolute workload of physical stress compared to untrained men (Deuster et al., 1989). Possibly, exercise-induced adaptations may also mitigate the responsiveness to other stressors, such as psychosocial stressors. In addition, future studies should control for the effect of central fat distribution (e.g., waist-to-hip ratio), as this factor has been shown to be related to greater psychological vulnerability to stress and cortisol reactivity (Epel et al., 2000).

In summary, we propose that physical activity is associated with reduced adrenocortical, autonomic, and psychological responses to a psychosocial stressor. In addition, the present study raises several issues that require further investigation. For example, future studies should include additional physical activity and metabolic measures for characterizing subjects. It would be desirable for future

research to further explore the interrelationship between physiological and psychological mechanisms on stress reactivity in physically active subjects (not only in elite sportsmen). This could lead to both a better understanding of stress-responsive physiological systems and to the development of multidimensional prevention programs (e.g., against stress-related disorders), which combine physical and cognitive coping strategies. Future prospective longitudinal studies might help to model this potential interaction linking sports activity, personality traits, cognitive coping styles, and stress responsiveness.

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## Conflict of interest

None declared.

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