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The Impact of Exercise on Hormones Is Related to Autonomic Reactivity to a Mental Task

L. Moya-Albiol,[1] A. Salvador,[1,2] E. González-Bono,[1] S. Martínez-Sanchis,[1] and R. Costa[1]

This study examined the effects of an acute physical stressor on salivary testosterone (Tsal) and cortisol (Csal) and their relationship with the autonomic responsiveness to a mental task in fit young men (n = *30*). *Salivary testosterone (Tsal) and cortisol (Csal) levels were determined before and after a maximal bicycle exercise. Heart rate (HR) and skin conductance levels (SCL) were continuously recorded before, during, and after a Stroop task. Tsal and Csal levels diminished while HR and SCL increased in response to stressors in all the sample. When subjects were distributed in function of their endocrine response to the physical stressor, high Tsal responders showed higher HR reactivity than low responders, and high Csal responders showed higher SCL reactivity and lower reaction time in the Stroop task. These results show that the influence of an acute physical stressor on hormones is associated with the autonomic responses to a mental task.*

KEY WORDS: physical stress; stress hormones; heart rate; skin conductance level; bicycle exercise.

INTRODUCTION

Exposure to stressful events leads to the activation or inhibition of several systems in the organism whose interrelation has been sparsely studied. It has been suggested that increases in testosterone after acute stress are mediated by the activation of the Autonomic Nervous System (ANS) in rats (Mayerhofer,

[1]Departamento de Psicobiología y Psicología Social, Universidad de Valencia, Spain.
[2]Correspondence should be directed to Dr. A. Salvador, Departamento de Psicobiología y Psicología Social, Facultad de Psicología, Universidad de Valencia, Apartado 22109, 46071 Valencia, Spain; e-mail: Alicia.Salvador@uv.es.

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Steger, Gow, & Bartke, 1992; Mayerhofer, Bartke, & Began, 1993) and baboons (Sapolsky, 1982, 1986), but this has not been verified in humans. Although cardiovascular illnesses have been associated with high levels of androgens in men (Cohen & Hickman, 1987) and women (Haffner, Katz, Stern, & Dunn, 1988), the majority of studies that have been carried out in men have failed to find significant relationships (Cauley, Guttai, Kuller, & Dai, 1987; Barrett-Connor & Khaw, 1988; Phillips, Yano, & Stemmermann, 1988). Recently, a positive relationship between cardiovascular and testosterone reactivity to different stressors in the laboratory has been reported (Girdler, Jamner, & Shapiro, 1997).

The study of the pattern of stress response in humans is facilitated by the use of laboratory stressors. Physical and psychological laboratory stressors such as bicycle or treadmill exercises and mental tasks have been commonly used (O'Connor, Petruzzello, Kubitz, & Robinson, 1995; Lovallo & Al'Absi, 1998; Buchanan, Al'Absi, & Lovallo, 1999; Carrillo et al., in press). Numerous studies have shown that testosterone and cortisol levels change in response to physical stressors. If the stressor is acute exercise, these changes depend on two types of factors: characteristics of the exercise—such as intensity, duration, and type—and subject's characteristics, such as physical fitness (Salvador, 1995). Acute moderate and high intensity efforts elicit testosterone increases (Cumming, Brunsting, Strich, Ries, & Rebar, 1986; Mathur, Toriola, & Dada, 1986; Häkkinen & Pakarinen, 1993; Wheeler et al., 1994), whereas longer submaximal exercises diminish it (Gugliemini, Paolini, & Conconi, 1984). If the exercise is maximal, these decreases are greater and could be intensified by social stress as found in competitive contests (Suay, Sanchís, & Salvador, 1997). Although cortisol levels are augmented by acute exercise of high intensity (Viru, 1992; Nieman et al., 1994), they may not vary or may even decrease in elite sportsmen after maximal physical exercise (Perna & McDowell, 1995).

Heart rate (HR) and skin conductance levels (SCL) are frequently used as valid indices of stress responsiveness to mental tasks (Kohlisch & Schaefer, 1996). HR responses to stress have been related to the onset and development of several illnesses, such as cardiovascular disorders (Al'Absi et al., 1997). Changes in electrodermal activity have usually been interpreted as evidence of cognitive or emotional changes (Hugdahl, 1995). Some studies have examined whether the acute physical exercise carried out in bicycle or treadmill exercise reduces the psychophysiological responses to mental stress. A lower cardiovascular reactivity (Duda, Sedlock, Melby, & Thaman, 1988; Roy & Steptoe, 1991; Steptoe, Kearsley, & Walters, 1993), as well as no effect on this variable (Roth, 1989), has been found. Nevertheless, no studies have investigated the connections between hormonal and electrophysiological responses to these stressors.

Considering all these findings, our purpose was to verify if the hormonal response to an acute physical stressor affects the electrophysiological response to a mental task in men. Although the majority of research has been limited to the electrophysiological response to stress, the current availability of salivary determinations has contributed to the fact that hormonal response is increasingly being taken into account. Based on animal research and on preliminary data obtained in men during a competitive laboratory task (Salvador et al., unpublished data), we hypothesised a positive relationship between salivary testosterone (Tsal) and HR, in which subjects with higher Tsal response to the bicycle exercise would have higher HR reactivity to the Stroop task. With respect to SCL and salivary cortisol (Csal), although no studies have reported a relationship between them, they could be associated due to the fact that both are adequate markers of distress. To this purpose, Tsal and Csal responses to a maximal bicycle exercise, as well as HR and SCL responses to the Stroop Color-Word Task, were studied in fit young men. Since it has been demonstrated that physiological responses to stressors in men are moderated by the level of fitness (Moya-Albiol et al., 2001), several physical variables were evaluated to control for possible changes in this level.

METHOD

Subjects

Thirty young, fit men who participated in different sports and trained between 10–15 hr a week were recruited through their coaches. All subjects were nonsmokers, free of medication, woke between 7–7.30 hr and did not train or practice exercise 36 hr before arriving at the laboratory. They gave informed consent approved by the Local Ethics Committee. The anthropometric characteristics of the sample are shown in Table 1.

Table 1. Mean (SD) of Anthropometric Characteristics

		Tsal responders		Csal responders	
	Total sample	High	Low	High	Low
Age (years)	20.57 (4.00)	19.70 (2.87)	23.40 (3.34)	18.80 (3.19)	22.30 (4.62)
Weight (Kg)	84.41 (10.79)	82.44 (12.61)	88.42 (8.43)	79.93 (8.45)	88.69 (7.19)
Height (m)	1.86 (0.10)	1.85 (0.10)	1.85 (0.08)	1.85 (0.09)	1.89 (0.08)
BMI (Kg/m^2)	24.28 (2.60)	24.06 (2.95)	25.71 (0.90)	23.48 (3.41)	24.77 (2.06)
Fat (%)	9.00 (2.85)	9.51 (3.29)	9.07 (2.53)	8.23 (3.06)	9.20 (2.70)

BMI = Body Mass Index.

Procedure

Each subject participated in one single session, which was carried out at the Sports Medicine Center (Cheste, Valencia, Spain) at the beginning of their respective sport seasons. The session lasted from 9.00 to 14.00 hr. Firstly, the subject provided the first salivary sample (9.00–9.30 hr). Secondly, a medical interview was carried out, and anthropometric measurements and resting HR (Kenz-ECG 302) and blood pressure (BP) (Speidel-Kellep) registers were obtained (9.30–11.00 hr). Afterwards, between 11.00–12.30 hr approximately, each subject performed a maximal bicycle exercise until voluntary exhaustion during which measurements of several physiological parameters were taken. After the test, the subject relaxed for 20 min before the collection of a second salivary sample. The subject was then conducted to another room, isolated from noise, and with constant temperature (22 ± 2 C) and humidity ($50 \pm 10\%$). There he carried out the Stroop task while HR and SCL were simultaneously measured (between 12.00–14.00 hr, approximately). The subject had to stay quiet and relaxed, seated in front of the computer where the task was presented and perform a 3-min practice with the electrodes fixed. After 10 min of relaxation, HR and SCL were measured for baseline (5 min), the task (5–6 min), and recovery (3 min).

Bicycle Exercise

The test consisted of three steps: a warm-up (load-free cycling at 60 rpm) lasting 4 min; an increase in the load every minute until voluntary exhaustion (9–16 min); and a 5-min recovery (load-free cycling). The exercise was performed on an electromagnetic cycle ergometer (Jaeger-Ergotest). The exercising subject was connected to a breath-by-breath analysis system (Sensor Medics MMC 4400 tc) to record the maximum oxygen uptake (VO_2 max). HR was monitored by a Hellige Servomed SMS 182 device using a three-lead ECG (CM5) and recorded at 1-min intervals. Lactate level was determined in deproteinized blood from an earlobe sample by a commercial kit (MPR2, Boehringer-Mannheim). Maximal lactate (LA max) was defined as the maximum concentration of three different samples taken in the minutes 1, 3, and 5 post-exercise.

Stroop Task

A modified version of the Stroop Color-Word Task composed of a practical didactic session and four assays with numeric and non-numeric stimuli (MacLeod, 1991) was used. The subject had to count the number of items included in each stimulus, ignoring distracters (numeric or not), as quickly as possible. Each response automatically elicited the next stimulus. Two performance parameters were computed: number of errors and reaction times.

Apparatus

Two silver-silver chloride electrodes for the skin conductance measure were fixed on thenar and hypothenar eminencies on the nondominant hand by adhesive rings. A low density gel (358") covered the sensitive part of both electrodes to enhance the conduction. Additionally, a sensor for the pressure detection was fixed to the ring finger of the same hand. The recording was performed by means of a Coulbourn Modular Recorder System (model S16-12, PA, USA) placed in another compartment of the room, out of the subjects' view. The Optical Pulse Coupler (S71-40) and the Tachometer (S77-26) were used for the acquisition and processing of the heart signal, respectively. The transducer was an IR-LED Phototransistor with a frequency of response oscillating between 0.5 to 10 Hz. A third module, the Skin Conductance Coupler (S71-22) was used for the transduction and registration of SCL. This module applies a constant 0.5 V excitation signal to the subject with an accuracy of ±0.1% and produces an output signal that represents conductance in mV per mmho.

Hormonal Determination

Saliva was directly collected from mouth to tube (Unitek^{R}) 5 min after stimulation by water and lemon juice. Samples were centrifuged (5000 rpm, 15 ± 2 C) and frozen at −20 C until determination by radioimmunoassay (RIA) at our laboratory (Central Research Unit, Faculty of Medicine, University of Valencia, Spain). Samples from each subject were run in duplicate in the same assay.

The Tsal assay required a previous extraction phase with ether. ^{125}I-testosterone tracer was added and decanted into a tube coated with a high specific antibody provided by a commercial kit (ICN Biomedicals, Costa Mesa, CA). Duplicate internal and external control tubes were routinely included in every assay. Tsal levels were expressed in pmol/l, and sensitivity was below 6 pmol/l.

Csal was determined by a commercial kit adapted as was recommended in the protocol (Orion Diagnostica, Espoo, Finland). ^{125}I-cortisol tracer and a high specific antibody were used. Csal levels were expressed in nmol/l, the sensitivity was 1 nmol/l, and internal and external controls were included in the assays.

Good precision was obtained with intra- and interassay variation coefficients below 5%. More details about hormonal determination have been described elsewhere (González-Bono, Salvador, Serrano, & Ricarte, 1999).

RESULTS

Data Reduction and Analyses

For hormonal levels, repeated measures ANOVAs with 'Time' (Basal/Post-exercise) as within-subjects factor were carried out, with Greenhouse-Geisser adjustments for degree of freedom where appropriate. To measure the magnitude of Tsal and Csal responses, the difference between postexercise and basal levels was calculated. For both Tsal and Csal, subjects who scored higher than 66th percentile were considered in the 'high responder' group, and those who scored lower than 33rd percentile were included in the 'low responder' group.

The physiological recording system registered 10 data points per second of each variable (HR and SCL). Mean values for each 30-s segment for baseline, task, and post-task were obtained using AcqKnowledge software averaging the last 3 min of baseline, the first 3 min of the task, and the 3 min of the recovery period. With respect to electrophysiological variables, repeated measures ANOVAs with 'Period' (Baseline/Task/Post-task) as within-subjects factor, using Greenhouse-Geisser adjustments for degree of freedom, were carried out to evaluate the effectiveness of the Stroop task. One-way ANOVAs were used as post hoc tests. Reactivity was assessed via simple change scores (task minus baseline) following recent recommendations (Linden, Earle, Gerin, & Christenfeld, 1997).

Differences among the established groups depending on their hormonal response (high and low Tsal or Csal responders, respectively) were calculated by one-way ANOVAs. ANCOVAs including those descriptive characteristics that were different among groups as a covariate were carried out for electrophysiological parameters, as in other studies (Burke et al., 1996; Litschauer, Zauchner, Huemer, & Kafka-Lützow, 1998).

All the analyses were performed by the SPSS 8.0 for Windows. Average values in the text are expressed as mean ± SD. The alpha level was fixed at .05.

Total Sample

Descriptive Characteristics

With regards to baseline physiological measures, all subjects were normotensive, as was indicated by the basal values of systolic and diastolic BP (120.67 ± 8.88 mmHg and 68.33 ± 5.14 mmHg, respectively). Their basal HR during the electrocardiogram was 51.60 ± 7.13 bpm. Tsal basal levels were included in a low-normal range (168.57 ± 64.04 pmol/l), whereas Csal levels were in a normal range (11.06 ± 6.17 nmol/l) in accordance with other studies (Read & Walker, 1984; Kirschbaum & Hellhammer, 1992; González-Bono et al., 1999).

Response to Stressors

The different measures evaluated in the bicycle exercise are presented in Table 2. When the total sample was considered, both Tsal and Csal decreased after the stressor, although nonsignificant differences between basal and post-exercise levels were found (Figure 1).

The Stroop task was effective in eliciting electrophysiological responses since the factor 'Period' was significant for both HR (Figure 2A) and SCL (Figure 2B), $F(1.26, 35.41) = 43.51$, $p < .05$ and $F(1.50, 37.39) = 37.35$, $p < .05$, respectively. Post hoc analysis showed that HR and SCL values increased when the stressor was introduced, $F(1, 28) = 32.95$, $p < 0.05$ and $F(1, 25) = 47.06$, $p < .05$, respectively, and recovery decreased $F(1, 28) = 56.24$, $p < 0.05$ and $F(1, 25) = 20.20$, $p < .05$, respectively, recovery levels being significantly lower in the case of HR and higher in the case of SCL relative to the baseline, $F(1, 28) = 24.73$, $p < 0.05$ and $F(1, 25) = 33.07$, $p < .05$, respectively.

Table 2. Mean (SD) of Measures in the Bicycle Exercise

		Tsal responders		Csal responders	
	Total sample	High	Low	High	Low
Maximum HR (rpm)	181.70 (9.48)	179.40 (9.47)	184.50 (11.53)	183.30 (11.19)	178.70 (6.88)
Systolic BP (mmHg)	181.67 (18.44)	183.00 (11.11)	183.50 (18.26)	186.50 (16.17)	186.00 (15.60)
Diastolic BP (mmHg)	80.83 (12.04)	78.50 (9.14)	82.00 (13.37)	83.50 (10.55)	79.00 (12.20)
Duration (min)	12.47 (1.74)	11.90 (1.52)	13.20 (1.75)	12.20 (1.69)	12.70 (1.95)
Maximal power (w)	309.33 (34.73)	298.00 (30.48)	324.00 (35.02)	304.00 (33.73)	314.00 (38.93)
VO_2 max (ml/min/kg)	43.07 (6.18)	42.40 (6.28)	42.16 (5.39)	46.52 (4.53)	40.96 (4.51)
LA max (nmol/l)	11.68 (2.25)	11.46 (2.04)	12.97 (1.76)	12.23 (1.73)	11.44 (1.71)

HR = Heart Rate; BP = Blood Pressure; VO_2 max = Maximum Oxygen Uptake; LA max = Maximal Lactate.

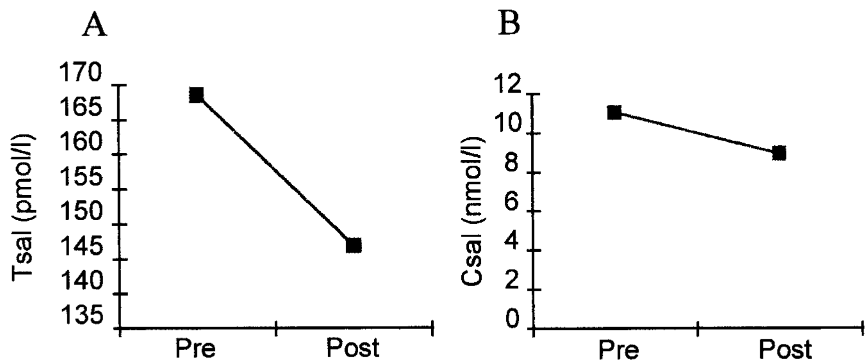


Fig. 1. Basal and postexercise levels of Tsal (A) and Csal (B) for the total sample.

High and Low Tsal Responders

Descriptive Characteristics

No significant differences between groups for weight, height, BMI, and fat were found, but low Tsal responders were significantly older than high responders, $F(1, 19) = 7.06$, $p < .05$. Baseline physiological measures did not differ between groups (Table 1).

Response to Stressors

No significant differences were found between groups for each measure evaluated in the bicycle exercise (Table 2).

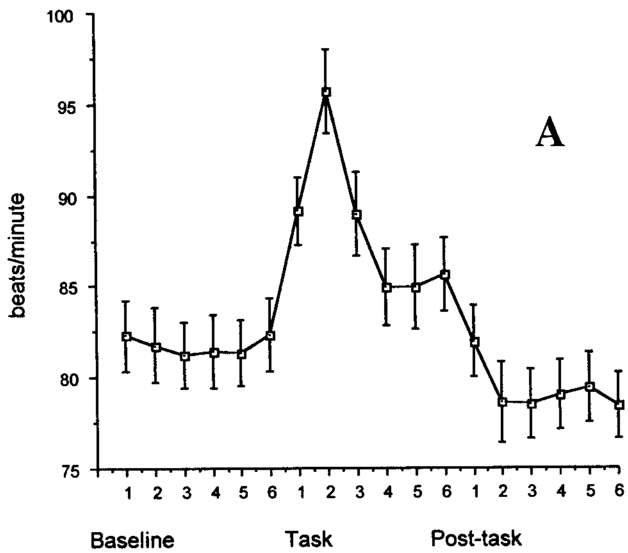
HR reactivity (Figure 3A) was significantly higher for high responders than for low responders, $F(1, 18) = 16.73$, $p < .05$, but groups did not differ in SCL reactivity. Due to the fact that age was significantly different between groups, HR and SCL analyses were repeated using this variable as a covariate, where similar results were found for HR reactivity, $F(1, 18) = 13.02$, $p < .05$.

Performance in the Stroop task was similar for both groups, with a similar number of errors, reaction times, and total time in carrying out the task.

High and Low Csal Responders

Descriptive Characteristics

With regard to anthropometric characteristics, weight was the only variable that differed between high and low Csal responders, the latter being significantly



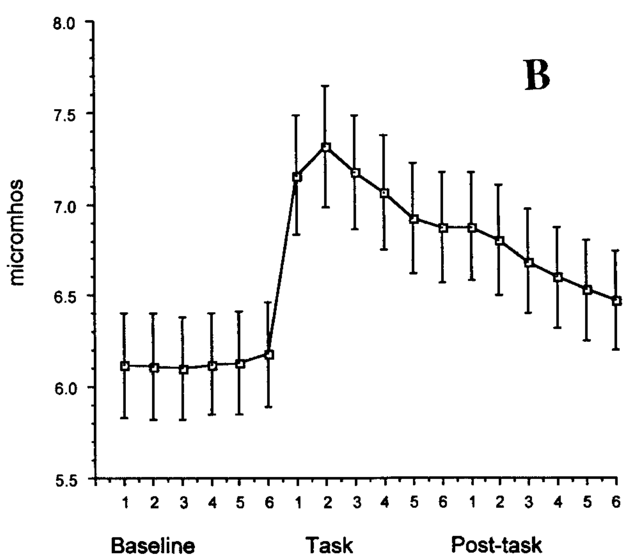


Fig. 2. A. Baseline, task, and recovery HR in the Stroop task for the total sample. B. Baseline, task and recovery SCL in the Stroop task for the total sample.

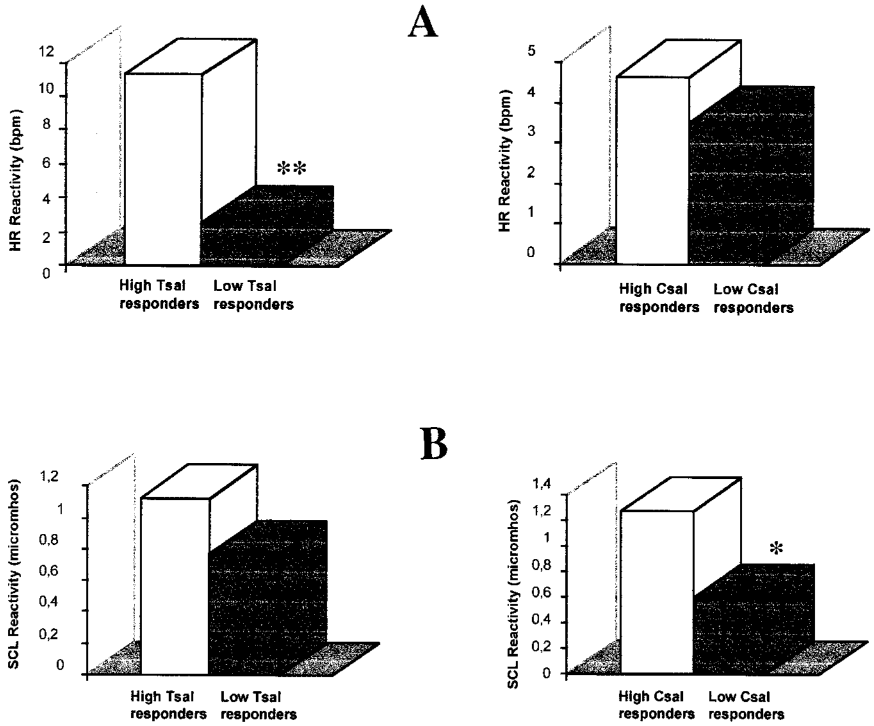


Fig. 3. A. HR reactivity for high and low Tsal and Csal responders. B. SCL reactivity for high and low Tsal and Csal responders.
$^*p < .05$; $^{**}p < 0.01$.

heavier, $F(1, 19) = 6.23$, $p < .05$. Baseline physiological measures did not differ between groups (Table 1).

Response to Stressors

High Csal responders showed higher VO_2 max in the bicycle exercise than low responders, $F(1, 19) = 7.55$, $p < .05$, (Table 2).

HR reactivity did not differ between groups, but a tendency to significance was found in the case of SCL reactivity (Figure 3B), where high Csal responders showed higher values than low responders, $F(1, 16) = 4.11$, $p < .06$. After repeating these analyses using weight as a covariate, the differences in SCL reactivity were significant, $F(1, 16) = 4.8$, $p < .05$.

High Csal responders compared to low Csal responders had lower reaction time in numeric and nonnumeric items of the Stroop task, $F(1, 18) = 19.07$, $p <$

.05 and $F(1, 18) = 16.04$, $p < .05$, and employed less time in carrying out the task, $F(1, 18) = 11.18$, $p < .05$.

DISCUSSION

The results confirm significant relationships between endocrine and autonomic responses to laboratory stressors in a group of fit young men. When all subjects were considered, the maximal bicycle exercise did not produce significant effects on the endocrine response, but the expected outcome for HR and SCL responses to a mental stressor was shown, with an increase when starting the task and a diminution in the recovery. In addition, hormonal and autonomic responses to a physical and to a psychological stressor, respectively, were related in specific ways, as the higher HR reactivity in high Tsal responders and the higher SCL reactivity in high Csal responders indicate. Moreover, high Csal responders showed higher VO_2 max and lower reaction time in the Stroop task.

There was a nonsignificant diminution in the Csal and Tsal levels in response to the bicycle exercise. Despite the fact that the few studies carried out in this field have described testosterone increases after high intensity acute exercises, it has been reported that when the effort is maximal the initial testosterone increment could be followed by a decrease (Fernández-Pastor, Diego-Acosta, & Fernández-Pastor, 1992). Moreover, since sportsmen carry out physical exercises until exhaustion, they would not perceive these efforts as highly stressful, and subsequently, the expected increments in cortisol after the exercise do not occur, as has been described (Perna & McDowell, 1995). There was an increment in the autonomic responses to the Stroop task measured through HR and SCL, a response pattern commonly observed (Tulen, Moleman, Van Steenis, & Boomsma, 1989; Sloan et al., 1997). The highest HR increments have been found in the first minute of the task, but the levels progressively decrease in this period. There is a task adaptation, a response pattern previously described (Szabó & Gauvin, 1992; Szabó, Brown, Gauvin, & Seraganian, 1993; Szabó et al., 1994). Similar to other studies (Puigcerver, Martínez-Selva, García-Sánchez, & Gómez-Amor, 1989; Steptoe et al., 1993), HR recovery was completed 3 min after the task period, due to the fact that generally recovery from cognitive tasks is faster than from emotional tasks (Vitaliano, Russo, Paulsen, & Bailey, 1995), although the good physical form of the subjects could also have contributed to the faster recovery (Linden et al., 1997). On the contrary, SCL recovery was not completed after this period, a finding observed in another study (Puigcerver et al., 1989).

Electrophysiological and hormonal responses to both physical and psychological laboratory stressors were related. Particularly, there was a relationship between cardiovascular and testosterone responses, a finding only described in another study using laboratory stressors (Girdler et al., 1997). In that study, serum testosterone responses to speech and arithmetic tasks were positively related to total peripheral resistance reactivity, but this was not found in the case of the Stroop task. In addition, testosterone response was not associated with the other evaluated cardiovascular measures such as systolic and diastolic blood pressure, stroke volume, and HR. We have found a positive association between salivary, nonserum testosterone levels and HR. Our results indicate that the effects of a maximal effort on testosterone levels are associated with HR responses to the mental task. In the light of these results—and taking into account the aforementioned studies carried out in animals—it seems that the ANS may be involved and consequently affect the Tsal response to stressors. Considering a more general view and applying these findings to the health risk associated with ANS reactivity, we can reinforce the previous studies that have related testosterone to the increase in the possibility of developing a cardiovascular illness (Cohen & Hickman, 1987; Haffner et al., 1988). It was also interesting to note that there was a relationship between SCL responses to the Stroop task and cortisol response to the bicycle exercise. This association would be interpreted in a context where both parameters, cortisol and SCL, are considered as markers of distress. Future research should go deeper into the links found between endocrine and autonomic measures and also consider sedentary or active persons who are representative of the general population. Studies examining androgens and cardiovascular function on the one hand, and cortisol and electrodermal profiles on the other, are needed to clarify the involvement of the ANS in the endocrine response to stress as well as the underlying mechanisms.

In sum, fit men did not show significant hormonal changes in response to a physical stressor, but their autonomic response to a mental stressor showed the expected pattern with an increase at the beginning of the task and a diminution when it finished. The relationship between endocrine and autonomic variables, and possibly with others not included in the study such as immunological variables, emphasises the importance of simultaneously studying several systems for a better understanding of the response to stress.

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