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Review

Coping with competition: Neuroendocrine responses and cognitive variables

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ABSTRACT

Confronting another individual or group motivated by the same goal is a very frequent situation in human communities that occurs in many other species. Competitive interactions emerge as critical situations that shed light on the effects and consequences of social stress on health. But more important than the situation itself is the way it is interpreted by the subject. This “appraisal” involves cognitive processes that contribute to explaining the neuroendocrine response to these interactions, helping to understanding the vulnerability or resistance to their effects. In this review, we defend the need to study human competition within the social stress framework, while maintaining an evolutionary perspective, and taking advantage of the theoretical and methodological advances in psychology and psychophysiology in order to better understand the cognitive processes underlying the social stress response in humans.

Contents

1. Introduction

In the past few decades, an increasingly large number of diseases and alterations have been associated with the stress experienced by subjects living in our advanced, industrialized societies. Acute and, particularly, chronic exposure to social stress has been related to the onset, maintenance or exacerbation of numerous and diverse types of dysfunctions that could lead to death (cardiovascular diseases, cancer, infections, etc.) or produce an important loss in quality of life (fibromyalgia, chronic fatigue syndrome, arthritis, etc.). Additionally, various mental disorders, such as depression or schizophrenia, among others, are highly

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influenced by chronic or acute stress events. In our more "aged" societies, stress has been considered an important factor that interferes with "satisfactory" aging, since it can contribute to cognitive impairment through detrimental effects on attention and memory processes, for example. Currently, aggression and violence are also being considered in relation to the pressure of stress and the lack of appropriate coping responses.

Charles Darwin (1859) highlighted that animal populations consist of individuals that differ from one another in their adaptive qualities and limitations. This variability in the potential to adapt to changing environmental demands is the central point of opposing aspects, the vulnerability and the resistance, even resilience, shown by individuals within a species. The value of psychosocial stress as a trigger for adaptive modifications was emphasized by Huether (1996). He also underlined that, from a short-term perspective, the stress response serves to increase the chances of survival of an individual who faces life-threatening situations, whereas from a long-term perspective, the stress response acts as a powerful tool for the elimination of unfit genotypes, either through stress-induced diseases or stress-induced infertility. This evolutionary approach is clearly supported nowadays (Korte et al., 2005).

In the last few years, stress research has incorporated new important concepts with strong repercussions at the conceptual and methodological levels. Allostasis, defined as the adaptive process for actively maintaining stability through change (Sterling and Eyer, 1988), fits quite well with the feelings and perceptions of stress in our accelerated changing industrialized societies. Allostasis is a fundamental process through which organisms actively adjust to both predictable and unpredictable events (McEwen and Wingfield, 2003). It is complemented with other concepts, such as the "allostatic load", which can be described as the cumulative impairment ("wear and tear") derived from the frequent or inefficiently managed activation of the mediators of the allostasis (hormones, neurotransmitters, cytokines, etc.) (McEwen, 1998). Complementarily, "allostatic overload" appears as a state in which serious pathophysiology can occur if it is chronically high. Based on the balance between energy input and expenditure, McEwen and Wingfield (2003) proposed two types of allostatic overload. Type 1 allostatic overload occurs when energy demand exceeds supply, resulting in the activation of the emergency life history stage; when the stressor passes, the normal life cycle can be resumed. Type 2 allostatic overload begins when there is sufficient or even an excess of energy consumption accompanied by social conflicts and other types of social dysfunctions. The second type is the case of human society and animals in captivity in certain situations and does not trigger an escape response. This implies that a specific environmental condition may differentially affect allostatic loads in different individuals.

Along with the recognized effects and consequences of stress, important research has been carried out on the stimuli and events capable of producing these effects. Stressors of a social nature have become a vital issue requiring our attention. This development has favored the recognition or denomination of a specific research field, Social Neuroscience, bringing together researchers from different disciplines interested in working in the interface among the biological, behavioral and ecological fields. 'Social Neuroscience' appears in the title of various recent books and scientific papers, including a new journal with this title that appeared in 2006. Many of the subjects and topics included in these sources have been studied for decades, but now this interdisciplinary background can contribute to increasing knowledge and applications to our social life.

Competition, implying that one or more individuals carry out some actions directed toward achieving a goal by confronting another individual or group of the same species motivated by the same goal, is a quite frequent situation in human communities or groups at different levels of "civilized" development. Competition plays an important social role, not only to get primary reinforcements (such as food), but also to obtain other secondary resources, such as employment, promotion and admission to prestigious universities. These secondary resources ultimately make it possible to get the best primary resources. Human competition is common, although the ways of interaction may differ from the more primitive organized groups to the more advanced industrialized societies, from direct aggression and violent acts to the use of subtle or Machiavellian strategies.

This review examines the research carried out on human competition in order to emphasize the role of cognitive variables and improve our understanding of the neuroendocrine responses involved. We propose that a re-location of these studies from the very interesting, but theoretically narrow, initial scenarios to another more general framework of social stress within recent theoretical formulations on stress research will make it possible to advance the knowledge about this type of response. Current interest in knowing more about vulnerability vs. resistance to pathological social stress effects recommends examining more in depth the appraisal processes involved and the coping response selected when faced with the stressor. Within an evolutionary-based context that includes the knowledge gained from very different species, we are now interested in incorporating the advances made in the field of Psychology, and more specifically, in the study of cognitive components of the stress response. We agree with Ursin (1998) that it is necessary to take into account the developments from Psychology in order to broaden and deepen the knowledge within the field of Psychoneuroendocrinology, and especially to understand the processes involved in the stress response. In our opinion, it is essential to consider different analysis levels that would contribute to a more complete understanding of competitive behavior. We will start our revision by analyzing the general framework of social stress and, especially, some of the recent advances related to the main consequence of the agonistic interactions, the social status or hierarchy. The concept of social status has increasingly been recognized both in animal and human research as being quite relevant to better understanding the impact on health.

2. Studying social stress

Social stress or social conflict is a chronic, recurring factor in the lives of virtually all higher animal species (Blanchard et al., 2001). Its pattern of behavioral and physiological effects may be qualitatively different from those motivated by other types of stressors, and it has potentially severe pathological repercussions for individuals in many species. Competitive or agonistic interaction is a clear example of social stress. Studying agonistic encounters and/or analyzing the resulting social hierarchies have improved our understanding about the effects of social stress on different physiological systems, as well as the individual differences (Sgoifo et al., 1999, 2005).

In the laboratory, competition for food, water or mating and, mainly, agonistic interactions have been employed to evaluate the social status of pairs or groups of animals, especially rodents. In this context, the Kudryavtseva sensory-contact model is worth noting. It is based on the development of aggressive and submissive types of behavior in male mice as a result of the acquisition of repeated experiences of social victories or defeats in daily agonistic interactions (Kudryavtseva, 1991, 2000). A recent variant incorporate a natural behavior of male mice, i.e. acquiring and defending a territory, including resident/intruder dyads that chronically live in sensory contact and physically interact on a daily basis (Bartolomucci et al., 2005).

In humans, the study of the individual differences in stress response has also shown a preference for laboratory contexts, although natural or real-life stressors have been used in some studies. Among others, such as the attention tasks (for review see Biondi and Picardi, 1999; Moya-Albiol and Salvador, 2001), a public speaking/arithmetic task combination (Trier Social Stress Test, TSST) with a strong evaluative component emerges as a strong psychosocial stressor (Kirschbaum et al., 1993). In this task, individuals have to deliver a speech for a job application (Corporation, School, Department, etc.) to introduce themselves to the selection committee, demonstrating why they think they are "*the best applicant*" for this position. Therefore, this test has an important competitive component, although opponents are not simultaneously present. In a review of 208 acute psychological laboratory stressor studies in humans employing meta-analytic procedures, Dickerson and Kemeny (2004) concluded that the capability of TSST to produce consistent cortisol increases was mediated by the presence of social evaluation and outcome controllability.

As mentioned above, exposure to acute, intermittent and, especially, chronic social stress has been associated with different dysfunctions and disorders. However, being exposed to social stress does not automatically predict subsequent pathological consequences. There is evidence that among many individuals experiencing stress, only a sub-population will progress to disease. Thus, determining the relationships between social factors and individual vulnerability to chronic social stress exposure is a productive way to shed light on the factors determining individual disease susceptibility (Bartolomucci, 2005; Bartolomucci et al., 2005). Social status resulting from the competitive/agonistic interactions is one of the key factors moderating individual variability in a great diversity of animal species (Creel, 2001).

3. Social status

Among the major advantages of living in social groups, social support and cooperation stand out, although there are also significant disadvantages arising from social conflict and competition. Social order reduces hostility and intra-species conflicts, social stratification and the underlying processes being traditionally related to testosterone (T) (Kemper, 1990; Ellis, 1994).

In social species, agonistic behavior displayed during social interactions plays a fundamental role in determining and/or maintaining the social position or dominance of an individual within a group (Koolhaas et al., 1980). During the fight and after its outcome, winning animals experience different responses in comparison with defeated animals (Henry et al., 1986). Furthermore, victory in successive interactions leads to a dominant position in the social hierarchy that includes certain behavioral patterns and physiological characteristics, whereas defeat leads to a subordinate position with a different pattern (Henry and Stephens, 1977). Since these pioneer studies, differences between dominant and subordinate individuals, with their potential consequences for health, have been established at different levels, especially in rodents: behavioral (social and non-social), physiological (weight and size of organs, cardiovascular parameters, temperature, sperm quality, etc.), neuroendocrine (hormonal levels and responses), neuro-chemical (monoamines, amino-acids, receptors, etc.), neurological (c-fos, hippocampal cell proliferation) and immunological (Azpiroz et al., 2003; Cornwallis and Birkhead, 2007; Hoshaw et al., 2006; Korte et al., 2005; Kozorovitskiy and Gould, 2004; Martínez et al., 1998; Moles et al., 2006; Stefanski, 2000). Thus, the effects of social status have been established by comparing subjects in different positions of the hierarchy (dominant vs. subordinate animals) typically on the basis of differences in their stress experience.

Social defeat is considered the main model for studying social stress in rodents due to its ecological and ethological validity (Miczek et al., 1991), also being employed as a good model of depression (Coventry et al., 1997; Kudryavtseva and Avgustinovich, 1998; Willner, 1993). It is worth noting that behavioral and physiological changes experienced by the dominant animal have attracted much less attention. Although there are exceptions, there is a tendency for dominating males to have lower cortisol (C), higher T and higher secondary sexual features than subordinate males (Virgin and Sapolsky, 1997). But, as Sapolsky has warned, the rank difference in T concentrations is generally more consistent in rodents than in primates, possibly due to their lesser degree of social and cognitive complexity. Additionally, when such differences in rank occur, it is not clear how much they are attributable to stress-induced suppression of T concentrations in subordinates or elevation of concentrations in dominants, since both aggressive interactions and sexual behavior are powerful stimulants of T secretion (Sapolsky, 2001).

Other subtle effects of social context have emerged from Sapolsky's research, such as stable or unstable conditions; in the latter, both dominants and subordinates show increased C levels. Moreover, the potential risk of losing rank in the hierarchy is inherently stressful, while gaining rank is not, although there are exceptions, such as a highly aggressive individual entering the group and gaining positions through continuous fighting (Sapolsky, 2002). The pronounced variation in the relationship between social status and physiological stress measures among primate species led Sapolsky and co-workers to ask "Are subordinates always stressed?" (Abbott et al., 2003). In answering this question, they performed an "informal" meta-analysis to identify the social variables that predict overactive, diminished or even stress-free responses in the subordinates. They identified two variables that significantly predicted higher relative C levels in subordinates, high rates of harassment by dominant animals and few coping outlets, including decreased opportunities for social support. Furthermore, the authors concluded that the social meaning of "rank" and its physiological correlates vary across different primate species. Finally, they emphasized that these studies had been carried out on primates living in captivity or in a particularly benign ecosystem in the wild (that is, with few or no stressors attributable to hunger, illness or predation), and these primates probably had particularly high occurrences of potentially stressful social interactions, given their close proximities. Thus, this situation is very similar to many present-day human societies (type II allostatic overload). Based on the available data on free-ranging animals, Goymann and Wingfield (2004) concluded that it is the relative allostatic load of social status that predicts whether dominant or subordinate members of a social unit will express higher or lower concentrations of glucocorticoids (GLU). They also pointed out that overall allostatic load may be influenced by many other factors, such as increases in metabolic demands or personality characteristics. Differences in the availability and effectiveness of coping responses have especially been associated with differences in GLU concentrations and allostatic load (Abbott et al., 2003; Koolhaas et al., 1999; Sapolsky, 2002).

In sum, the assumption that subordinates are more stressed than dominants must be modified depending on the species considered and the general social context. In contrast with some initial findings and reinforcing the importance of the global social context, recent studies of cooperative breeders in the wild show that dominant individuals have elevated GLU more often than subordinates do. These findings have at least two repercussions

(Creel, 2001). First, they complicate the conventional view of social stress, with broad ramifications for the evolution of dominance and reproductive suppression. Second, they demonstrate that winner–loser studies carried out with animals in captivity do not necessarily predict relationships between social status and basal stress hormone levels for stable social groups in the wild.

Like nonhuman primates, humans organize their social groups so that some individuals are more highly regarded and have higher status relative to others. Social hierarchies exist within human groups across cultures. For humans, social acceptance is essential for survival, whereas social exclusion has catastrophic consequences; however, the price of social relationships is that individuals must comply with the social norms, and at every level of the hierarchy, they have to submit to those above them (Roy, 2004). Moreover, each individual usually participates in several different hierarchies.

The most significant objective measure is socioeconomic status (SES), which has been consistently related to health; low SES has been characterized by more environmental challenges and fewer psychosocial resources, leading to sustained psychobiological activation (greater autonomic and neuroendocrine activation) and loss of a dynamic capacity to respond to new challenges, which would promote chronic stress diseases (Kristenson et al., 2004; Roy, 2004; Steptoe and Marmot, 2002). However, it is worth noting that feeling poor, more than being poor, a concept called 'subjective social status' (SSS), seems to better predict stress-related health outcomes (Gruenewald et al., 2006; Sapolsky, 2004; Singh-Manoux et al., 2003; Wilkinson, 2000).

Psychobiological responses to psychosocial threats related to social status have been studied in laboratory and work settings (Adler et al., 2000; Kunz-Ebrecht et al., 2003; Steptoe and Marmot, 2002), reporting more consistent results when recovery measures, instead of reactivity measures, of cardiovascular variables (heart rate, HR and blood pressure, BP) have been employed (Steptoe et al., 2002, 2005). Status can be conferred in humans, as in lower animals, through power, dominance and ability to influence by means of a threat-based, agonistic system that relates to accessing resources (Gilbert, 1997). In recent years, some of these dimensions such as implicit power motive (Schulteiss et al., 1999, 2004, 2005) and dominance (Josephs et al., 2003, 2006; Mehta et al., 2008), have been studied. The complexity of the social status, its determination, and the importance of the subjective interpretation of numerous dimensions related to it, present a great challenge for research in humans.

4. Human competition: evolutionary theoretical background

Before briefly reviewing the main results obtained on this topic, we will mention the theoretical background for the research performed on humans. Two very attractive, important hypotheses within an evolutionary approach have guided this research. The studies have been carried out mainly with men, with only a few studies on women, although both hypotheses defend the possibility of being applied to females as well.

4.1. Biosocial status hypothesis

This hypothesis was initially formulated by Mazur (1985) and Mazur and Booth (1998) as a model to explain the establishment of social status in primate groups. It argues that, in competitive situations, victory would lead to increases in T, whereas defeat would produce decreases. Consequently, in the winners their dominance and tendency to participate in future social encounters would increase, while the losers would develop submissive signs with a diminished tendency to fight. Thus, high T levels would facilitate aggressive, dominant behaviors that would favor getting or maintaining a higher position in the social hierarchy, whereas subjects with previous experiences of failure would show low T levels, which would diminish the probability of initiating new agonistic encounters. The outcome obtained, victory or defeat, is the factor that will determine the ongoing behavior. Mazur (1985) indicated that the social status in primates is established through face-to-face interactions, by means of signs that include stable attributes or actions and postures. Among the biological responses considered, Mazur also named C, and even the thumb blood volume (TBP), as a measure of the sympathetic nervous system, in relation to stress experienced.

4.2. Challenge hypothesis

In the past few years, the challenge hypothesis has been incorporated into the research on this topic. It was originally proposed to explain the T-aggression associations in birds with a monogamous mating system (Wingfield et al., 1990). This hypothesis maintains that T levels increase in specific contexts associated with aggression in order to support reproductive physiology and behavior. These increases, in turn, facilitate aggressive behavior related to territory formation, dominance disputes and mate-guarding (Wingfield et al., 2000). The hypothesis takes into account aggressive, sexual, parental and social behaviors, suggesting T changes related to their functional meaning. It has inspired recent research on the relationships between T and these behavioral categories in humans, including competition (see van Anders and Watson, 2006).

5. Studies on competition in humans

From an evolutionary approach, the parallelism between the agonistic or social aggression displayed by individuals of other species and that displayed in human sports competitions has been emphasized (Kemper, 1990; Nelson, 1996). Based on this idea, the majority of the research on the "competition effect" was carried out in the sports context, although more recently an increasing number of studies have been developed in the laboratory setting. It is worth noting here that the two most important dimensions of the TSST, the main psychosocial stressor employed in human research nowadays, namely social evaluation and outcome controllability, are included among the main characteristics of sports competitions (see Kemper, 1990). The effects of winning or losing have been studied, especially on T levels, with only some studies incorporating C measures, although it is progressively being studied more and more. Furthermore, an increasingly large number of studies have been carried out in the laboratory, which facilitates including other measures requiring some technical recordings not previously employed in sports competitions, such as cardiovascular parameters.

Taken as a whole, the results obtained do not reflect a clear, unanimous panorama, reporting T increases in winners, no statistically significant differences between winners and losers, and even T increases in losers (see Table 1), with very rare significant results in C levels. There are important methodological differences among studies that make direct comparisons difficult, such as the time interval between T measures in relation to the competition or even noticeable statistical insufficiencies (Archer, 1991). Several (moderating or mediating) intervening variables have been proposed, including physical effort, relevance for status, motivation to win, mood, causal attribution, personality and trait characteristics and coping styles (see Salvador, 2005). In order to avoid the effects of physical effort and improve the control of other confounding factors, a number of studies have been carried out in

Table 1
Studies on impact of sports and laboratory competitions on hormonal and cardiovascular variables, in men and women (modified from Salvador, 2005.).

Studies	N & sex	Experimental situation	Measures & results
Sports			
Mazur and Lamb (1980)	8 E	Tennis matches (doubles)	T: ↑ in W, ↓ in L
Elias (1981)	15 E	Wrestling matches	T: ↑ in W; C: ↑ in W
Salvador et al. (1987)	14 E	Judo combat	T: n.s.; C: n.s.
Campbell et al. (1988)	8 E	4 Wrestling matches, 4 cycloergometry	T: ↑ in L
Booth et al. (1989)	6 E	Tennis matches (singles) in 6 meets	Tsal: ↑ W ↓ in L
Salvador et al. (1990)	17 E	Judo combat	T: n.s.; C: n.s.
Mazur et al. (1992)	16 E	(a) Chess tournament	(a) Tsal: ↑ in W> ↑ in L
	8 E	(b) Chess tournament (in 9 meets)	(b) Tsal: W > L after sixth event
Suay et al. (1999)	28 E	Judo combat	T: n.s.; PRL: n.s.; C: W > L
González-Bono et al. (1999)	16 E	Basketball	Tsal: n.s.; Csal: n.s.
Passelergue and Lac (1999)	15 E	Wrestling competition	Tsal: n.s.; Csal: n.s.
González-Bono et al. (2000)	16 E	Basketball	Tsal: n.s.; Csal: n.s.
Serrano et al. (2000)	12 E	Judo competition	Tsal: n.s.; Csal: n.s.
Filaire et al. (2001)	18 E	Judo champioship	Tsal: L > W; Csal: n.s.
Bateup et al. (2002)	17 F	Rugby (in 5 meets)	Tsal: n.s; Csal: W < L
Kivlighan et al. (2005)	23 E, 23 F	Rowing ergometer	Tsal: E ↑, F n.s.; Csal: E and F ↑
Kivlighan and Granger (2006)	21 E, 21 F	Rowing ergometer	Csal: ↑; α-amilase: ↑
Edwards et al. (2006)	22 E, 18 F	Soccer competiton	Tsal: ↑ in E W and F W & L Csal: ↑ in E W and F W & L
Laboratory			
Mazur and Lamb (1980)	14 E	Lottery	T: n.s.
Gladue et al. (1989)	39 E	Reaction time[a]	Tsal: W > L in all task
McCaul et al. (1992)	28 E	Coin toss[a]	Tsal: ↑ in W n.s.
	101 E		Tsal: ↑ in W
Mazur et al. (1997)	28 E, 32 F	Tennis video game	Tsal: n.s.; Csal: n.s.
van Anders and Watson (2007)	37 E, 38 F	Computed vocabulary.	(a) Tsal: ↓ in E L, F n.s.
	31 E, 43 F	Outcome (a) real, (b) random[a]	(b) Tsal: n.s.
Ricarte et al. (2001)	13 E, 53 F	Role-playing game	HR task: W > L

Abbreviations: T = plasma testosterone, Tsal = salivary testosterone, C = plasma cortisol, Csal = salivary cortisol, PRL: prolactin, W = winners, L = losers, E = men, F = women.
[a] Outcome manipulated.

the laboratory employing different types of tasks (time-reaction, lottery, video games, etc.). In these studies, the results are not unanimous either (Table 1). Finally, studies on competition in women are scarce with inconclusive results. In sports competitions, no responses or T increases in both winners and losers have been found. With regard to C, increases in losers compared to winners or increases in all women have been reported. In the laboratory, neither T nor C responses have been found. To our knowledge, cardiovascular response to the outcome has been considered in a study on negotiation. We did not find significant differences in BP, but the winners displayed HR increases during the task and decreases after the task that did not appear in losers; this was interpreted as part of an active and effective coping (Ricarte et al., 2001).

In his review, Archer (2006) included a meta-analysis of a subsample of fifteen papers with which effect sizes could be calculated for one or more of the comparisons where rises in T were expected. First, during the competition, the increase in T was greater for sport competitions than for contrived competitive situations involving a monetary reward. Second, comparing winners and losers in a subsample and removing the largest outlier (Filaire et al., 2001), the difference reached statistical significance. Archer (2006) concluded that, although sport produces larger increases in T than a contrived competition does, overall winners and losers differ more after contrived competitions than after sport competitions.

In the laboratory studies, there are several important aspects to take into account. First, the outcome of some tasks depends on the performance, while the outcome of others depends entirely on chance (e.g., reaction-time vs. coin toss). Second, in some cases where the subject thinks the outcome depends on his/her performance, it is actually being manipulated experimentally. In the laboratory studies reviewed, significant effects were only found when the outcome depended on chance (McCaul et al., 1992). In their first paper, Mazur and Lamb (1980) concluded that the T increases would appear only in merit situations that involved the personal effort of the individual. This assumption has been maintained in the research carried out in sports contexts, where merit and performance are considered basic dimensions of the outcome (Kemper, 1990), which is also the sense derived from the evolutionary perspective. In all of these contexts, the outcome stems from the subject's behavior; consequently, he/she has at least partial control over it. This question raises a pivotal point in the stress literature, the perception of control.

5.1. Importance of the cognitive variables

There is an ample consensus that the stress response depends to a high degree on how the event is interpreted. If it is "appraised" by the individual as threatening to his/her physiological or psychological balance, a measurable physiological response will be produced (McEwen et al., 1993). Mason (1975) emphasized that the perception of the situation is the main factor in the neuroendocrine variability and activation. This aspect has been consistently emphasized in human stress research (Biondi and Picardi, 1999; Dickerson and Kemeny, 2004; Kudielka and Kirschbaum, 2007; Day and Walker, 2007), although it has also reached animal stress research (Veissier and Boissy, 2007). A key concept has been the control and, more specifically, the perceived control, which has emerged as a powerful explanatory variable in stress research. Perceived control is relevant to a wide variety of settings, from basic experimental research on neuroendocrinology, for example, to the experience of people in different socioeconomic sectors of society (Steptoe, 2000).

As we mentioned above, in studying human competition, very different conditions related to the subject's control over the outcome have been included. In order to advance the knowledge about the consequences of this situation, we aimed to compare the psychobiological responses to two similar tasks with the same monetary reward, but designed so that individuals attributed their outcomes to effort or to chance. Fifty-six young male university students participated in a 120-min experimental session. The 28 participants in the competitive task were instructed repeatedly that their outcome depended on their performance and effort. The other 28 subjects participated in another computerized task whose outcome, according to the instructions, was determined by chance. In both tasks, outcome was manipulated by the experimenter in order to produce a clear outcome. We measured HR, BP, T and C, as well as mood assessed by PANAS, before, during and after the tasks depending on each measure. Men who participated in the "effort" competition showed significantly higher T levels, Systolic and Diastolic BP values and HR than the subjects who participated in the "chance" task. Furthermore, they significantly reduced their positive mood, which did not happen in the "chance" competition (Salvador et al., in preparation). Consequently, men showed a clearly different response pattern when participating in the two different competitions, which differed in the subjects' perceptions of their control over the outcome ("control perceived"), but not in the distress produced, as they appraised the "effort task" as a "challenge" (Tomaka et al., 1997). The HR responses found coincide with the greater HR reactivity reported in a few studies when the same task was presented in competitive conditions in comparison with other non-competitive conditions (Beh, 1998; Harrison et al., 2001; Veldhuijzen van Zanten et al., 2002).

The innovative research on control and coping by Weiss (1972) provides evidence for the importance of cognitive factors in determining the endocrine response to stress. The role played by perceived control has been amply studied, and its consequences in relation to health have been recognized. Thus, in the same handbook where the concept of allostasis appeared, Fisher (1988) proposed a model of the routes from cognitive factors (perception of control) to mental disorders and physical illness. One route from high control, mediated by catecholamines, leads to ulcers and heart diseases, while another low control route, mediated by catecholamines, ACTH and cortisol, would lead to cancer and infectious illness through immunological incompetence. However, control is not the only relevant cognitive variable. The ongoing research invokes different cognitive processes, from the primary cognitive comparison of the immediate external event with some cognitive representation based on prior experiences, to other much more complex processes, such as expectancies or response outcomes that can exert profound influence on the magnitude and direction of the stress response (Levine, 2000). Stress-related emotions and neuroendocrine responses result from a series of evaluations of the triggering situation that the individual makes based on criteria including novelty, predictability, controllability and others (Scherer, 2001; Aue et al., 2007). Among them, complex cognitive processes, such as primary and secondary appraisal (Lazarus and Folkman, 1984), deserve special mention, as well as some other developments (see Blascovich and Tomaka, 1996). The situation the individual is faced with is evaluated based on the expectancies attached to it and to the possible actions available to this particular individual. Consequently, to a large degree, stress response depends on previous experience and how it is interpreted. In our view, all these factors are clearly valid and relevant to competition. When a person is faced with a competitive situation, his/her previous experience, including performance and outcomes in similar situations, accompanies him/her, consciously or unconsciously, and significantly conditions his/her response pattern in the current situation. Thus, it is necessary to take this background into account, in order to more closely examine the role played by specific factors suggested by the competition research, such as causal attribution or relevance of status, among other factors related to personality and trait characteristics of the individuals involved.

In the 'cognitive activation theory of stress' (CATS), this experience or learning is defined either as stimulus expectancy or response outcome expectancy. According to its proponents (Ursin and Eriksen, 2004), brains store relationships between stimuli (classical conditioning) or between responses and their outcomes (instrumental conditioning). Previous success produces "coping" or positive response outcome expectancy, whereas lack of success produces expectancies of failure. Other possibilities are "helplessness" (when no relationship between acts and results is experienced), and "hopelessness" (if the individual learns that all acts lead to disastrous results); both are associated with "sustained arousal" and potential sensitization processes. On the contrary, coping defined in this way is associated with low stress levels and general good health. In this theory, the stress response itself should be understood as an alarm occurring within a complex cognitive system with feedback and control loops, no less but no more complicated than any of the body's other self-regulated systems (Levine and Ursin, 1991). Here we find very interesting theoretical formulations with concepts to apply to our understanding of neuroendocrine responses to competition, as we progress in the formulation of a general conceptual framework (see Fig. 1).

5.2. Coping and response patterns

Although from our approach to this topic T is of special importance, no one hormone responds to the demands in an isolated way (Charmandari et al., 2005); indeed, hormones respond as a part of multiple and concurrent responses that can be organized into patterns of neuroendocrine responses (Mason, 1968). The two main neuroendocrine axes activated in response to stress, sympathetic adreno-medullary (SAM) and HPA, have been related to "different and relatively independent dimensions of the hormonal activation in the coping to stress" (Weiner, 1992). The SAM, activated during the "effortful" coping with a stressor, implies increases in the HR and in the BP, together with the liberation of adrenaline and noradrenaline. The activation of HPA is associated with the inability to cope, distress and despair, and the perceived uncontrollability to cope is associated with the liberation of ACTH and cortisol. In the same sense, Lundberg and Frankenhaeuser (1980) described two factors obtained by factorial analysis of data from 48 male and female university students. The "distress factor" involves elements of dissatisfaction, boredom, uncertainty and anxiety, and it is associated with a passive attitude, a moderate positive loading in cortisol, a low positive loading in epinephrine and a high negative loading in norepinephrine excretion. The "effort factor" involves elements of interest, engagement and determination; it implies an active way of coping, a striving to gain and maintain control, with a high positive loading in epinephrine and low positive loadings in norepinephrine and cortisol excretion. These two factors were confirmed in other studies employing strong, acute stressors, such as parachute jumping and a swimming test for non-swimmer recruits (Ellertsen et al., 1978; Vaernes et al., 1982). It is worth mentioning that in both studies a T factor was found. Afterwards, a third factor, "effort without distress", was characterized by increases in epinephrine and decreases in cortisol (Frankenhaeuser, 1986).

As described above, since the pioneer studies of James Henry it has been evident that dominant male mice were more active and responded to social interactions with a predominantly SAM pattern, whereas subordinate males were less active and predominantly responded with an HPA pattern (Henry and

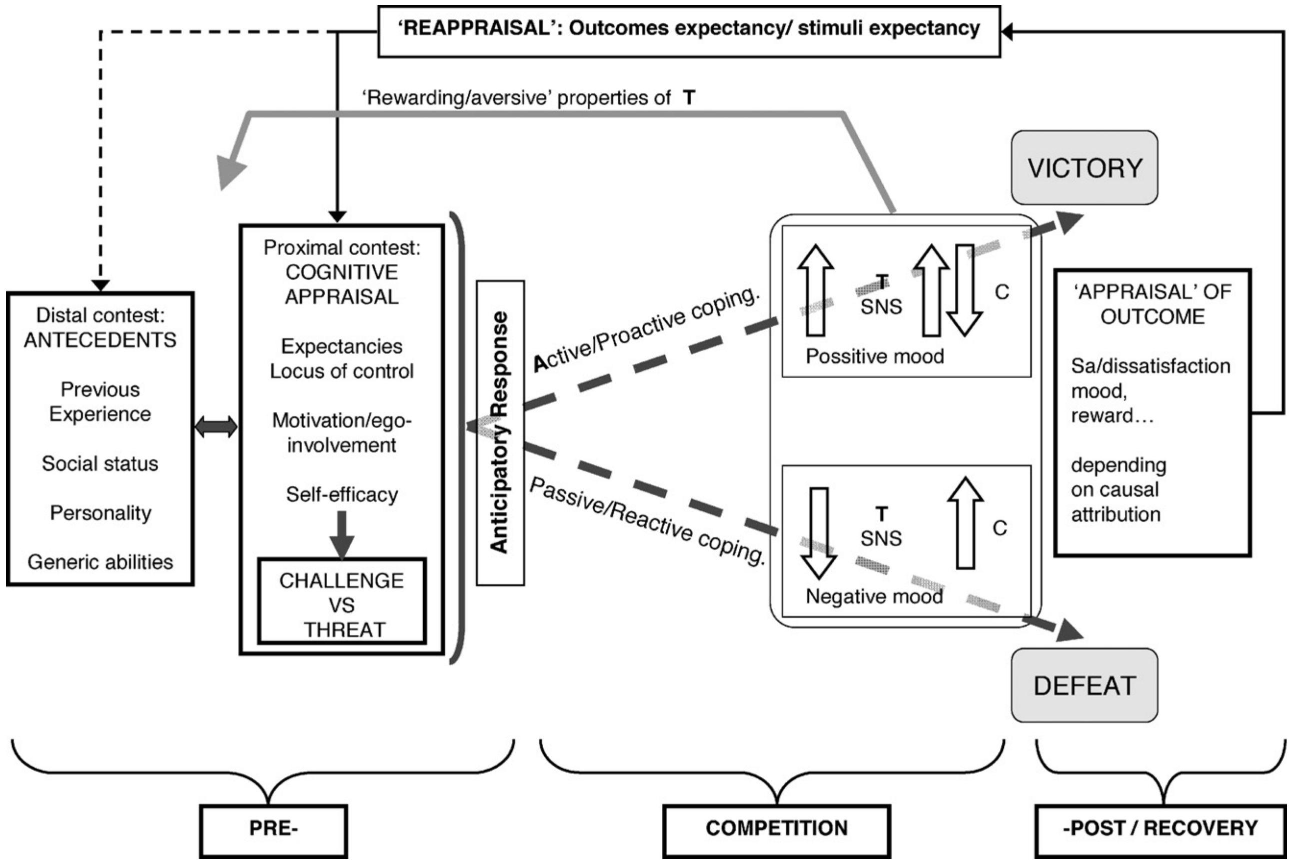

Fig. 1. Model of neuroendocrine and mood responses to a competitive situation (modified from Salvador, 2005).

Stephens, 1977). According to Koolhaas and Bohus (1989), who included aggressive/competitive behavior among the coping responses, there are two extreme coping strategies (active or proactive vs. passive or reactive). The active strategy is characterized at the behavioral level by "fight or flight" and at the physiological level by high basal levels of T and noradrenalin and a high reactivity of SNS, represented by the reactivity of the plasma catecholamines and the BP. The passive strategy is characterized by scarce social activity and even immobility, and at the physiological level by a parasympathetic response, greater HPA response and reduced levels of T. In 1999, Koolhaas and co-workers considered the possibility that the distinctions between proactive and reactive coping styles represent rather fundamental biological trait characteristics that can be observed in many species (Koolhaas et al., 1999). Much more recently, they maintained that coping styles can be considered as trait characteristics that are stable over time and across situations, they can be identified in a range of species, and they have a clear ecological validity (Koolhaas et al., 2007; Korte et al., 2005), which matches the current interest in behavioral syndromes (Sih et al., 2004). These formulations agree with the model proposed by Henry (1992), who also included the T within the neuroendocrine patterns of response (see differences between the neuroendocrine responses of Hawks and Doves to acute threat in Korte et al., 2005, pp. 7). The stress-coping styles are being analyzed in the interface among physiological, behavioral and cognitive variables (Overli et al., 2007).

As has been mentioned, T was included in several main stress response patterns, and it has acquired a key position in the studies by Koolhaas and co-workers on coping styles and neuroendocrine responses. In their research, individual variations in aggressive behavior are considered a variation in actively coping with environmental challenges. Thus, highly aggressive individuals adopt a proactive coping style, whereas low levels of aggression would indicate a more passive or reactive style of coping (Koolhaas et al., 2007). From our perspective, this result agrees with some studies on stress related to challenging situations in men (Ellertsen et al., 1978; Vaernes et al., 1982), and we think it could be extended to competitive situations. The relevance of T for aggressive behavior and its role in agonistic interactions in animals and humans has been clearly established (Archer, 1991, 2006; Booth and Mazur, 1998; Brain, 1990; Martínez-Sanchís et al., 1998, 2003; Salvador and Simón, 1987; Salvador et al., 1994, 1999; Wingfield, 2005). Sapolsky reported that, with the onset of a stressor, T levels promptly declined in subordinate males, but transiently rose in dominant ones (Sapolsky, 1991), which he based on the rank-related differences in SNS function and testicular blood flow. He also established that, during periods of hierarchical instability, dominant males had the highest T levels and did not show lower basal GLU, thus being more likely to develop different pathologies (Sapolsky, 2004). This resistance of the testicular axis to the suppressive effects of stress has been related to mating (reviewed in Wingfield and Sapolsky, 2003), although fluctuations in T levels within the normal range have been found to have remarkably few effects on reproductive physiology and behavior in primates (Sapolsky, 2004). Recently, the importance of the contribution of a noradrenergic type of stress reactivity in the transitory increase of T in the initial stage of stress has been emphasized (Chichinadze and Chichinadze, 2008), in addition to the absence of chronic stress and the ability to manage stress situations, among other factors mentioned, such as dominant status.

Furthermore, in our opinion, the functions served by the increased T require more research in order to be empirically established, probably attending to more subtle effects on the brain, such as anxiety and fear or arousal, which are clearly relevant in competitive situations. But other processes involved in the appraisal processes and the establishment of expectancies might be also affected. According to Ursin and Eriksen (2004), to establish response outcome expectancies, an instrumental conditioning between responses and their consequences is established. T may also have a role in storing relationships between stimuli (classical conditioning), thus producing stimuli expectancies.

Here we will briefly describe some findings about the rewarding characteristics of T in rodents, in order to defend their role in these conditioning processes in relevant social situations such as competitions. Previously, we reported that low doses of T have rewarding properties in OF1 male mice without aggressive experience and with the experience of only one agonistic encounter (Arnedo et al., 2000, 2002). Employing the sensory-contact model, OF1 young male mice without aggressive-experience were submitted during 5 consecutive days to a 10-min daily agonistic encounter. During these 5 days, dominance-subordinate status was established in each pair of mice; significant differences between the two groups of animals in aggressive and submissive behaviors, as well as in T and corticosterone levels, were verified (see Rodriguez-Alarcón et al., 2007 for details about the procedure). After this, a conditioning place preference (CPP) paradigm was established in order to test the rewarding properties of low doses of T in animals after experimentally modifying their expectancies of winning or losing by means of defining their status as dominant vs. subordinate. We found that low doses of T were rewarding for dominant animals, but not for subordinates (Fig. 2) (Rodriguez-Alarcón and Salvador, 2003), with these properties being at least partially mediated by dopamine (Rodriguez-Alarcón, 2008). These findings lead us to think that T could amplify appetitive or aversive effects of social behaviors, thus contributing to discrimination between social interactions that could finish in victory or in defeat (Johnson and Wood, 2001; Wingfield, 2005). We speculate that, due to previous experience in social encounters, specific expectations are generated, which would lead to fighting or to avoiding an interaction; the T response when facing the appropriate stimulus (co-specific) would be integrated within (active vs. passive) the coping strategy adopted by the individual. If there is a perspective of success, it is more likely that the strategy will be active, contact and attack will be established, and there will be a rewarding T increase. On the contrary, if the previous experience has been one of repeated defeats, the individual would probably avoid the encounter and not present offensive behavior, offering submissive signs, which would be accompanied by an absence of response or maybe an altered sensitivity to T. Then the T response would be associated with expectations; thus it would be anticipatory and not the consequence of the outcome of the interaction Salvador et al. (2003). T could act on brain structures and circuits that are common to reward and social behavior (e.g., the amygdale, the nucleus accumbens and the medial prefrontal cortex). There are data about an anticipatory response of T to the mere presence of a co-specific or even a stimulus associated with it.

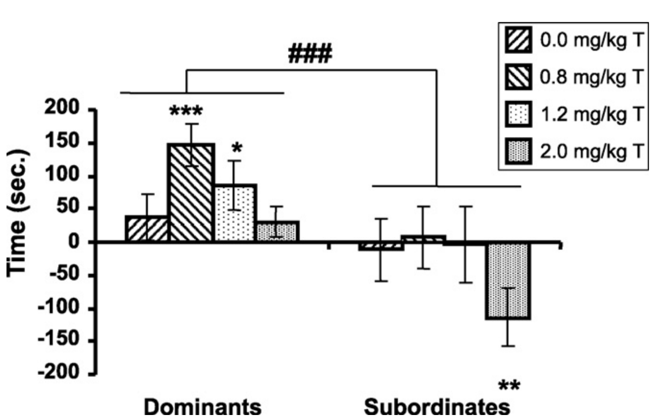

Fig. 2. Differences in the rewarding properties of T in dominant and subordinate mice depending on T doses administered (Rodriguez-Alarcón, 2008).

5.3. Competition as a social stress situation

Competition has been understood as a stressful situation in the animal and sports literature, where both the competition and its outcome are considered very significant stressors. In fact, in their review, Biondi and Picardi (1999) included sport competitions as real-life stress conditions, among others amply cited in the stress research, such as academic examinations or parachute jumping. Recently, Salvador (2005) proposed integrating competition within a more general stress framework, considering that previous results on this topic can be better explained as a part of the coping response to competition. From this perspective, if the individual appraises the situation as important, controllable and depending on his or her effort, that is, if he/she interprets the competitive situation as a challenge, an active coping response pattern is more likely to develop. This pattern would be characterized by increases in T and sympathetic nervous system (SNS) activation, accompanied by positive mood changes, all of which would increase the probability of victory although obviously it is not guaranteed. On the other hand, if the individual assesses the situation as threatening or uncontrollable, he/she will probably present a passive coping response pattern characterized by insufficient T and SNS activation and increases in C, accompanied by negative affect changes. This appraisal and the associated responses will increase the probability of defeat. Additionally, outcome finally obtained will be able to affect on mood and satisfaction. Obviously, the appraisal in a specific situation is the result of the interaction between many dimensions and variables, probably some not at conscious levels that have been mentioned throughout this review and others. Moreover, the probability of success or lack of it associated with the response pattern will depend on the specific demands and processes involved in the specific competition in question. Finally, the emotions associated with the outcome obtained would depend on aspects such as the importance of the competition, motivation to win, status, etc. Post-competition complex cognitive evaluations may strongly moderate the psychobiological responses during the recovery period, such as the attribution processes.

In our opinion, the re-location of the human competition research within the current stress framework would make it possible to improve the conceptualization of many different moderating or mediating factors suggested by previous studies.

6. Conclusions

In this review we aimed to underline some key developments and advances obtained in the animal research on social stress, in order to demonstrate the convenience of re-locating the research on human competition within the stress background. Nowadays, knowledge is being integrated from different disciplines, which provides us with an opportunity to take advantage of an interdisciplinary approach (e.g., Social Neuroscience). Hence, in studying human competition, we consider it necessary, while keeping without losing the evolutionary background in mind, to incorporate conceptual and methodological advances, including assessment, obtained in Psychology. Throughout the last few years, a clear progressive introduction of cognitive or psychological concepts (perception, appraisal, and, more recently, coping and even personality or behavioral syndromes) has occurred in animal research. Therefore, it is imperative for the research on human competition to take a similar path by addressing the higher complexity of the cognitive processes and social organization of our species. Advances in cognitive sciences could provide a strong impetus to our understanding of this social behavior.

Research on human competition started in an evolutionary context employing observational methods (Who won or lost?), but empirical findings progressively showed that it was more essential to find out how the individual perceived, appraised, controlled and experienced the importance of competition or the outcome, in order to understand the neuroendocrine response. These and other cognitive processes are involved in triggering differentiated patterns of response. In our first study on this topic (Salvador et al., 1987), we only observed the fighter's behavior and the outcomes (winning or losing), expecting to find the hypothesized relationship: victory associated with T increases and defeat with T decreases; we did not ask about expectancies or control. We only found differences depending on the sports status, but when we studied this variable specifically, it was insufficient to explain the hormonal responses (Salvador et al., 1990). Only when we started to ask about motivation to win, causal attribution of outcome and satisfaction did we start to explain part of the hormonal response variance (González-Bono et al., 1999, 2000; Serrano et al., 2000; Suay et al., 1999). This need to take into account the individual's cognitive processes has been increasingly considered in the studies on this topic, but when their findings are analyzed, a puzzle with a lot of missing pieces still appears. We think that there are a lot of interesting potential intervening variables mentioned (see Archer, 2006; Salvador, 2005; van Anders and Watson, 2006) that could be tested in the laboratory with an acceptable experimental manipulation, as well as other key questions, as recently published (van Anders and Watson, 2007). For this purpose, methods and assessment instruments from psychology and psychophysiology would be very useful.

Our review also indicates that there is a void in relation to competition in women, in spite of the fact that in our advanced societies their incorporation into social contests is clearly increasing. As has been indicated in many studies on these contexts, women are no less competitive than men (Cashdan, 1998) There is also an urgent need, in order to understand the possible health consequences, to take into account the sex differences reported in stress responses (Blehar, 2006; McDonough and Walters, 2001; Troisi, 2001). Sex or gender, as well as socialization experiences (Gunnar and Quevedo, 2007), are important variables to consider in understanding the individual differences in (competitive) stress responses and, together with other stable, trait-like characteristics, shed light on the vulnerability and/or resistance to this social stressor.

Cognitive processing facilitates the internal milieu to meet perceived and anticipated demands. Although anticipatory responses, due to space limitations, have not been properly addressed in this review, they are of great importance in the overall process. In humans, at least some aspects are being studied that mainly focus on predicting performance in very competitive fields, such as sports (e.g., Eubank et al., 1997; Blascovich et al., 2004), within stress models based on the challenge-stress appraisal (Dienstbier, 1989; Tomaka et al., 1997).

Finally, it is worth noting that victory experienced by (dominant) animals in successive encounters facilitates aggressive behavior (shorter latency and longer duration). The sensory-contact model in mice has shown a strong potential to produce dominant, very aggressive animals that display a pathological violence against a co-specific. It is necessary to delve into the underlying neurobiological mechanisms of this social behavior, taking into account the rewarding/punishing dimensions of social interactions and their outcomes.

In summary, advancing in the understanding of human competition, its cognitive antecedents, its psychobiological response patterns and its more basic neurobiological mechanisms, will allow us to increase understanding about the basis of individual differences, as a way of improving and addressing their potentially negative effects, thus preventing this allostatic overload.

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