CHAPTER

1

Psychobiology of Physical Activity: Integration at Last!

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Psychobiology is defined here as the integrative study of behavior from the social, cognitive, and biological levels of analysis. This is a broad scientific field that encompasses psychophysiology, psychoneuroendocrinology, psychoneuroimmunology, physiological psychology, behavioral genetics, and several areas of neuroscience.

The struggle for integration between mind-focused and body-focused approaches within all branches of psychology has been long and arduous. It could be argued that, when examined from a historical perspective, the integrative psychobiological approach has enjoyed modest popularity within psychology and exercise science and has not yet lived up to its full potential for informational yield. This appears to be the result of an interesting paradox, with considerably more researchers seemingly willing to extol the wondrous advantages of integrative research than to undertake truly integrative and systematic psychobiological research.

In his presidential address, delivered during the first meeting of the Society for Psychophysiological Research on September 5, 1961, and later published in the inaugural issue of the journal *Psychophysiology,* Chester Darrow (1964) acknowledged that psychophysiology had not had the impact that the psychophysiologists themselves had envisioned. Nevertheless, he expressed the hope that, one day, "psychophysiology will be able to define so-called 'mental mechanisms' in psychoneurophysiological terms" (p. 7). He continued by stating that "then no longer as in decades past, will indulgent 'pure' psychologists superciliously inquire 'what has neurology or physiology revealed of importance regarding the working of the mind?'" (p. 7). In the same issue and along similar lines, Albert Ax (1964) admitted that "few of the physiological referents for psychological concepts are known in detail" (p. 9). Expressing a similar sentiment a few years later, in his presidential address to the American Psychosomatic Society on March 21, 1970, John Mason (1970) stated that "realistically, we must face the fact that the psychosomatic approach has not as yet had the sweeping, revolutionary impact on medicine of which it appears capable" (p. 427).

In contrast to these earlier views, however, contemporary assessments seem to reflect the substantial progress that has taken place in the interim. Taking stock of the achievements of modern psychophysiology, for example, Cacioppo, Tassinary, and Berntson (2000) noted that, although "there are undoubtedly psychological, social, and cultural phenomena whose secrets are not yet amenable to physiological analyses" (p. 4), "psychophysiological research has provided insights into almost every facet of human nature" (p. 5).

Arguably, progress also has been made in the integrative psychobiological study of human functioning within the contexts of exercise and sport. In the first comprehensive proposal for a psychophysiological orientation in sport psychology, Hatfield and Landers (1983) noted that "very few problem areas within sport and motor behavior have seen . . . psychophysiological approaches systematically applied" (p. 243). More than a

decade later, Dishman (1994) similarly noted that "there has been very little use of biological psychology traditions and methods in exercise science" (p. 52). The present volume, the first of its kind and the product of a gestation phase that lasted for decades, is a reflection of the progress that has taken place.

The Progress of Scientific Investigations

Overall, and despite the progress that has been made in the last 35 years or so, the study of physical activity from a psychobiological perspective, relative to research from other perspectives, has had a limited impact on exercise science. Psychobiological studies make up only a small fraction of the articles published in exercise science journals. For example, only 3.9% of the articles published in *Medicine and Science in Sports and Exercise,* the official journal of the American College of Sports Medicine, between 1969 and 1993 could be classified in the area of psychobiology (Morgan, 1994a). Moreover, of these, the majority represented a single topic, namely perceptions of exertion. Similarly, training in psychobiological theories and procedures is provided in only a very small number of graduate programs in the exercise sciences (Sachs, Burke, & Schrader, 2000).

Likewise, psychobiology has been only a small area within the subdisciplines of sport and exercise psychology, typically given little space in journals and, at times, treated as a "fringe" area in conference programs. Sport and exercise psychology grew as scientific fields primarily under the dominant influence of the social-cognitive "revolution" in general psychology (Gardner, 1987; Johnson & Erneling, 1997). Still today, these areas of research continue to be influenced heavily by the social constructionist metatheory (Gergen, 1985) and associated self-report and qualitative methods of data collection.

Examples of the lack of appreciation for the psychobiological approach by proponents of social cognition and social constructivism are commonplace in the literature. With regard to research on emotion, for example, commenting on a model of emotional responding proposed by LeDoux (1986), which focused on the amygdala as a key structure, Lazarus (1986) stated that "neurophysiological concepts are generally inadequate templates for psychological concepts" (p. 245). Within this general context, psychobiology has been discarded by some as either irrelevant (i.e., not having anything substantive to contribute within the social constructionist framework) or having a low potential of informational yield, especially when considered in relation to its complexity and requisite investigative effort.

This disposition is puzzling, especially when the object of scientific study is *physical* activity. Exercise and sport inherently involve the body and mainly center around the physical nature of the body. Therefore, it is clear to us that an adequate understanding of *physical activity* cannot emerge if we limit the scope of the investigation to cognitive and social factors and dismiss the role of the body and the brain. We hold this position to be self-evident. From a truly integrative psychobiological standpoint, there is no conflict or mutually exclusive relationship between different levels of analysis. Although psychobiology does attribute ultimate causation to the brain and nervous system, it also accepts that all methods, including those of the biological, physiological, neuroscientific, and social-psychological traditions, have their place. This is nicely exemplified in the following excerpt by Cacioppo and colleagues (2004):

> *"All human behavior, at some level, is biological but this is not to say that biological reductionism yields a simple, singular, or satisfactory explanation for complex behaviors, or that molecular forms of representation provide the only or best level of analysis for understanding human behavior. Molar constructs such as those developed by the social sciences provide a means of understanding highly complex activity without needing to specify each individual action of the simplest components, thereby providing an efficient means of describing the behavior of a complex system." (p. 399)*

It has been said, and we agree, that unless psychology and cognitive theories of the mind are consistent with neuroanatomy and neurophysiology, they can degenerate into an "empty boxology" (Lang, 1994, p. 219), an assortment of boxes and arrows lacking in credibility and validity as models of cognition and behavior. Conversely, a psychobiological approach does not automatically bestow upon a psychological study objectivity or instant scientific value. Good psychobiology must have solid, well-informed psychological principles and hypotheses at its core (see Ursin, 1998, for

an example in psychoneuroendocrinology). As John Mason (1970) reminded the members of the American Psychosomatic Society,

> *"although the physiologic approaches . . . may offer some important strategic assets, I hope it is clear that these research approaches can accomplish very little by themselves. It cannot be overemphasized that the principal task before psychosomatic research remains, first and foremost, the analysis of psychologic processes. The physiologic approaches should be viewed as mere adjuncts by comparison." (p. 435)*

Secondary Ignorance and Dualism

As noted earlier, this volume was literally decades in the making, as the psychobiology of exercise and sport grew to its current critical mass. One may wonder why the long delay in appreciating the value of psychobiological approaches and why the slow rate of progress. The reasons are many, and they are not necessarily obvious or unanimously agreed upon. Here we concentrate on two that we deem particularly critical. However, as we enter this discussion, we must make clear that searching for factors that might have prevented a higher rate of progress implies no criticism toward the field and its hard-working investigators. Inhibitory forces are a typical and essentially unavoidable part of the evolution of any field, and they are certainly not the making of a particular individual, group, or school of thought.

First, we focus on the absence of an appropriate educational infrastructure and, specifically, graduate programs and courses with an emphasis on the psychobiology of physical activity. This has resulted in psychobiological approaches that seem to reflect what Dishman (1990) astutely characterized "secondary ignorance," namely the notion that the right answer, theoretical concept or measurement approach, is out there in the literature but the fields of exercise and sport psychology are not aware of it. This has resulted in research attempts that have been unsystematic and ineffectively designed, thus often leading to dead ends. Eventually, the absence of meaningful findings has led to disappointment and the abandonment of the research question. Both sport and exercise psychology have seen several examples of this phenomenon.

In sport psychology, Hatfield and Landers (1983, 1987) commented on the widely held yet clearly erroneous assumption of an undifferentiated and unidirectional arousal response, which had resulted in an "overly simplistic perception of psychophysiological measurement" (1983, p. 245). Several studies in sport psychology in the 1970s and 1980s examined the correlations between various electrophysiological indices of arousal and self-reports of anxiety. Not finding a significant relationship, researchers were quick to reject the psychophysiological measures as uninformative. For example, expressing the general sentiment at the time, Martens (1987) stated that "certainly, physiological and biochemical measures have not been the answer, not for a lack of trying to make them work" (p. 47). Perhaps such measures did not "work" because, as Hatfield and Landers noted, researchers in sport psychology had not fully appreciated some fundamental principles of psychophysiological responses, such as the law of initial values, and individual and situational response specificity (Lacey, 1956), despite the fact that these had been fairly well established in the literature by that time.

In exercise psychology, a similar frustration and eventual abandonment of a line of research occurred with the widely publicized endorphin hypothesis for the exercise-induced "feel-better" effect (Hoffmann, 1997; La Forge, 1995; Morgan, 1985). In their simplest form, studies attempting to test the hypothesis that the "feel-better" effect was mediated by endogenous opioids did so by correlating the levels of circulating beta-endorphin with absolute scores or changes in scores on various self-report measures of mood. It is perhaps not surprising that these studies did not yield significant relationships, as most seem to have ignored highly important findings from neuroanatomy and neurophysiology—for example, that peripheral levels of beta-endorphin do not necessarily reflect (or influence) the dynamics of central opioids. Even the generally more sophisticated studies that attempted to manipulate central opioids by administering blocker agents (naloxone or naltrexone) had several problems, again due to an apparent lack of critical input from psychopharmacology. For example, the dosages of blockers and the timing of their administration (preexercise, postexercise, or intravenous drip during exercise) appear to have been selected arbitrarily. Once again, the failure to arrive at consistent and unambiguous findings has led investigators to the premature discontinuation of

this line of research. Nevertheless, despite these problems, an author not only concluded that the endorphin hypothesis was a "myth" but also felt that the evidence was strong enough to justify the sweeping generalization that "physiological explanations for an improved mood after exercise do not fit any longer" (Stoll, 1997, p. 119).

The second problem is encapsulated in one distressing yet familiar term: dualism. As Dishman (1994) noted, the absence of systematic psychobiological research is "consistent with a dualistic view of mind and body adopted by exercise scientists. . . . Segregation of biological and behavioral methods cannot advance our knowledge . . . and must end" (p. 52). Dualism is perhaps the single most elusive, potent, and persistent adversary of progress. Over the years, there has been a seemingly endless stream of passionate quotes from leading figures in sport and exercise psychology condemning the evils of dualism. And yet, dualism evidently remains alive and well, not just in sport and exercise psychology but also in general psychology and neuroscience.

One particular variant of dualism, which the philosopher Drew Leder (1990) called "ontovaluational dualism," appears to be especially prevalent within sport and exercise psychology. This term is meant to convey that in this type of dualism, besides the familiar ontological notion of mind and body as distinct entities, there is an implicit or explicit valuation such that either the mind or the body is assumed to have primacy or a commanding role over the other. Consider, for example, the role of physiological processes in social-cognitive theory. According to Bandura (1997, p. 107), physiological processes within the body only acquire meaning for the individual once they are cognitively evaluated within the mind. As Lee (1995) put it, by not only separating the mind from the body but also placing the two in an antagonistic relationship with the mind in a commanding role, Bandura essentially seems to have reduced the individual to "a collection of subjective experiences, with a body more or less tacked on as a way of getting around" (pp. 261-262).

In sport and exercise psychology, one often has to read between the lines to uncover the subtle but unmistakable signs of dualism, veiled under a rich antidualism and prointegration rhetoric. Both varieties of ontovaluational dualism are present, one ascribing primacy to the mind and one to the body. At the risk of oversimplifying, one could say that the vision of integration that seems to emerge from many writings is not one in which the two sides meet somewhere in the middle, taking advantage of their collective theoretical treasure and methodological arsenal, but one in which it is suggested that proponents of the "other side" should abandon their views and methods and accept "ours." Although such exhortations are undoubtedly well intentioned, a skeptic might argue that they are also not the most effective way to achieve integration. As an example, no one could argue with the consensus-building potential of the following statements that reject dualism: (a) "A psychobiologic approach usually will be more fruitful than either a biologic or a psychologic model alone" (Morgan, 1983, p. 46) and (b) "It seems judicious to encourage the study of both biological and social cognitive variables simultaneously" (Rejeski & Thompson, 1993, p. 12) since "social cognition and human biological responses are reciprocal systems that cannot be studied in isolation—not if we are to reject dualistic thinking" (Rejeski & Thompson, 1993, p. 28).

This consensus is weakened, however, when such statements are accompanied by others that seem to move away from the direction of integration, reflecting one of the two varieties of ontovaluational dualism. As an example, with no criticism intended, a researcher approaching the study of behavior in the context of sport and exercise from a social-cognitive perspective might interpret statements such as the following as questioning the importance of the perspective that he or she represents: "Especially those who rely exclusively on cognitive psychology, seem to believe that the head does not have a body" and "If one waits a little while, a dump truck will surely back up with cognitive psychology scattered throughout its hold, along with numerous self-efficacy and self-appraisal measures" (Morgan, 1989, p. 100). Conversely, a researcher with a biological perspective might feel alienated or confused after reading that "[a model proposing that] the origin of all subjective experience [is] rooted in physiological substrata" is "*unfortunately* . . . reductionistic" (Rejeski & Thompson, 1993, p. 18, italics added). Reductionism seems to have acquired some negative connotations. Yet reductionism really means believing that "complex phenomena are best understood by a componential analysis which breaks down the phenomena into their fundamental, elementary aspects" (Reber, 1985, p. 622). Somehow this is often interpreted as an assumption that psychological phenomena should be reduced to the study of physiology (Brustad, 2002; Dzewaltowski, 1997). Thus, perhaps not unexpectedly,

this causes a strong negative reaction among the proponents of the social-cognitive and constructivist approach. We believe that a truly integrative psychobiology can be founded only on genuine respect for the unique insights accessible from each of the multiple levels of analysis (Cacioppo & Berntson, 1992). Arguably, calls for integration juxtaposed with positions that could be viewed as rejecting the value of other viewpoints or levels of analysis are bound to be ineffective and ultimately work against the common goal of advancing the science. As Cacioppo and colleagues (2000) put it, "The abyss between biological and social levels of organization is a human construction, however, one that must be bridged to achieve a complete understanding of human behavior" (p. 830).

To summarize, sport and exercise psychology have not been immune to the problems that have delayed and hindered the application of psychobiology in other areas of psychology. But perhaps due to the limited size of the field, the delays have been prolonged and the internal tensions regarding ways to overcome dualism have resisted efforts toward mutual understanding and compromise. As we noted, the unsophisticated early attempts at psychophysiological investigations of arousal and anxiety and the various manifestations of ontovaluational dualism are not unusual phenomena or unique to sport and exercise psychology. Viewed from a historical perspective, they are par for the course, frustrating yet unsurprising obstacles on the way toward an evolved and mature science. The present volume represents a clear demonstration of the progress that the field has made.

Sport Psychology

A comprehensive review of the psychobiological investigations conducted in sport and exercise psychology in the previous 35 years is beyond the scope of this introductory chapter. However, we do wish to provide a context in which the cutting-edge research presented within this text can be appreciated. We limit our coverage to six themes in sport psychology and six themes in exercise psychology. The original studies and literature reviews that we chose to cite are meant as representative examples and certainly not as an exhaustive list.

In sport psychology, the key outcome of interest is athletic performance. Therefore, the main themes relate, directly or indirectly, to the optimization of performance. A first prevalent theme refers to the study of various electrophysiological (e.g., electromyography, skin conductivity, heart rate, blood pressure) and neuroendocrine (e.g., catecholamines) responses associated with stress and anxiety. The main questions that have been examined include whether such variables relate to self-reports of state anxiety and whether they relate to or are predictive of performance in motor or athletic skills (e.g., Karteroliotis & Gill, 1987; Smith, Burwitz, & Jakeman, 1988; Weinberg & Hunt, 1976). As noted earlier, many of the studies in this early line of research were plagued by hypotheses that failed to take into account fundamental principles of psychophysiology, such as the law of initial values and response specificity. This research has been essentially discontinued in recent years, leaving behind more open questions than unequivocal answers. Unfortunately, the lack of consistent relationships between physiological measures and either self-reports of anxiety or indices of performance has left many in sport psychology with the impression that physiological measures entail too much effort for little eventual gain.

A second theme is reflected in studies with an applied orientation that examined the effectiveness of biofeedback techniques (typically involving heart rate, blood pressure, electromyography, skin conductance, and brain wave activity) for regulating competitive anxiety and enhancing performance (e.g., Daniels & Landers, 1981; see reviews by Petruzzello, Landers, & Salazar, 1991; Sandweiss & Wolf, 1985; Zaichkowsky & Fuchs, 1988). This research, which continues, albeit at a slower pace (e.g., Bar-Eli et al., 2002), has shown positive effects and has allowed the development of standardized intervention protocols (e.g., Blumenstein, Bar-Eli, & Tenenbaum, 1997).

A third theme focuses on the psychobiological manifestations of overtraining (O'Connor, 1997). This line of research has combined assessments of mood states and stress hormones, primarily cortisol, and has provided evidence of significant relationships between self-reports and hormonal assays (O'Connor et al., 1989). Recent studies have begun to extend this research to include the impact of overtraining and the associated psychological problems, such as depression, on immune parameters (Armstrong & Van Heest, 2002).

A fourth theme involves the examination of electrocortical activity as an index of attention and allocation of cognitive resources (e.g., Bird, 1987; Hatfield, Landers, & Ray, 1984; Konntinen & Lyytinen, 1992). This research, which is based on quantitative analyses of real-time electroencephalographic (EEG) data, has provided valuable

insights into skilled performance that would have been impossible to obtain through a self-report methodology. Over two decades of research (e.g., Deeny et al., 2003; Haufler et al., 2000; Hillman et al., 2000) have led to the formulation of a conceptual model based on the efficient use of cognitive resources in skilled performers (Hatfield & Hillman, 2001).

A fifth theme is conveyed in studies focusing on the association between psychological factors (e.g., anxiety or mood states) and either physiological (e.g., oxygen uptake) or biomechanical (e.g., movement kinematics) parameters (e.g., Beuter & Duda, 1985; Beuter, Duda, & Widule, 1989), including those associated with running economy (e.g., Crews, 1992; Martin, Craib, & Mitchell, 1995; Williams, Krahenbuhl, & Morgan, 1991). This research has uncovered some relatively reliable associations, and in turn these findings have prompted studies examining the effectiveness of intervention strategies, such as biofeedback or relaxation, designed to improve movement patterns, the metabolic efficiency, and ultimately performance (e.g., Caird, McKenzie, & Sleivert, 1999).

A sixth theme focuses on imagery. Based mainly on Lang's (1979) bioinformational theory, studies have examined the efferent signals and peripheral physiological changes associated with imagery (e.g., Gallego et al., 1996; Wang & Morgan, 1992). More recently, there has been an effort to integrate this research with emerging neuroscientific evidence in order to understand the brain mechanisms involved (Keil et al., 2000).

Exercise Psychology

In exercise psychology, which focuses on health and well-being, perhaps due to the historical associations of this field with such areas as psychosomatic and behavioral medicine, psychophysiology, and psychophysics, the impact of psychobiological approaches has been deeper and wider than in sport psychology. A first prevalent theme is the study of perceived exertion. Starting with the introduction of Borg's Rating of Perceived Exertion (RPE) scale in the United States in the early 1970s (Borg, 1973; Borg & Noble, 1974), this topic has become one of the most prolific areas of research within exercise science (Borg, 2001). Likewise, following the endorsement by the American College of Sports Medicine of RPE as a basic method of prescribing and monitoring the intensity of exercise, this scale has become one of the most commonly used measures in clinical practice. According to Morgan (1994b), "From the very beginning of Borg's pioneering efforts . . . the rating of perceived exertion . . . has been conceptualized as a psychophysiological phenomenon; and there is now an extensive research literature supporting the theoretical proposition that effort sense is best viewed within a mind-body context" (p. 1072). Substantial portions of the variability in ratings of perceived exertion can be accounted for by physiological variables indicative of the intensity of exercise (e.g., heart rate, ventilation, oxygen uptake, lactate; see Chen, Fan, & Moe, 2002). However, it is clear that both dispositional (e.g., personality traits) and situational (e.g., perceived social evaluation) psychological variables also play an important role (e.g., Morgan, 1973, 1981, 1983, 1994b). According to an integrative conceptual model, cognitive factors are expected to be particularly influential when the intensity of exercise is submaximal, whereas peripheral physiological cues are expected to dominate the perception of exertion at near-maximal intensity (Rejeski, 1981, 1985).

A second theme comes from numerous studies that have been conducted to test the psychobiological hypotheses proposed by Morgan (Morgan, 1985; Morgan & O'Connor, 1988) and Hatfield (1991) to explain the "feel-better" effects of both acute and chronic exercise. These include the monoamine hypothesis, the endorphin hypothesis, the thermogenic hypothesis, and the cardiac influence model (see reviews by Hatfield, 1991; Hoffmann, 1997; Chaouloff, 1997; Dishman, 1997; Koltyn, 1997; La Forge, 1995). Although the thermogenic hypothesis seems untenable and research on the endorphin and cardiac influence hypotheses appears to be on a hiatus, research on the monoamine hypothesis, focusing mainly on norepinephrine and serotonin, is ongoing and is producing promising results (Meeusen & De Meirleir, 1995; Meeusen, Piacentini, & De Meirleir, 2001). The emerging challenge is the integration of the various mechanisms into a meaningful model (La Forge, 1995).

A third theme focuses on the influence of aerobic fitness and aerobic conditioning on the psychophysiological reactivity to "psychosocial" or "mental" stressors (e.g., the Stroop task, mental arithmetic, public speaking). Based on the assumption that a higher level of stress reactivity would increase the risk for cardiovascular disease, numerous studies have been conducted to test

the hypothesis that aerobically fit or aerobically trained participants would exhibit a blunted stress response. Although some reviews indicated a modest effect in this direction (e.g., Crews & Landers, 1987; Sothmann et al., 1996), others have been critical of the methods and skeptical about the consistency of this effect (e.g., Dishman, 1994; van Doornen, de Geus, & Orlebeke, 1988). It has also been proposed that the nature (i.e., the familiarity, intensity, or controllability) of the stressor might play an important role, as fitness might increase, rather than decrease, the response to certain novel, intense, or particularly threatening stimuli (Dienstbier, 1989, 1991). Recent efforts have turned to an investigation of the central regulatory mechanisms of the stress response using animal models (Dishman, 1994; Dishman & Jackson, 2000).

A fourth theme involves examination of the effects of aerobic fitness and conditioning on cognitive performance. This research is of particular relevance to the aging population, as the ability to deal with cognitive challenges declines with age. Although the initial stages of this line of research involved behavioral measures, such as reaction time (see review by Etnier et al., 1997), psychobiological approaches, starting mainly with a series of oft-cited studies by Dustman and colleagues (Dustman et al., 1984, 1990), have been very influential. Following a seminal publication in *Nature* (Kramer et al., 1999) and a meta-analysis (Colcombe & Kramer, 2003) showing that the beneficial effect of exercise is selective, specifically affecting the tasks that involve a substantial executive control component, this line of research has seen a recent surge of activity, with hypothesis-driven studies that involve event-related potentials (Colcombe et al., 2004; Hillman et al., 2002) and brain imaging (Colcombe et al., 2003). At the same time, basic research is being conducted on the fascinating phenomena of exercise-induced neurogenesis (e.g., van Praag et al., 1999; van Praag, Kempermann, & Gage, 1999) and the action of brain growth factors (Cotman & Berchtold, 2002), processes that may underlie exercise-associated improvements in learning, memory, and problem solving.

A fifth theme involves the study of the phenomenon of exercise-induced analgesia and its underlying mechanisms. Shortly following the discovery of endogenous opioid peptides and the fact that their levels are elevated with vigorous exercise, researchers found evidence, in both rats (e.g., Shyu, Andersson, & Thorén, 1982) and humans (e.g., Janal et al., 1984), of a naloxone-reversible (i.e., opioid mediated) postexercise analgesic effect. Subsequent studies, treating exercise-induced analgesia as a case of the broader phenomenon of stress-induced analgesia and using forced swimming (e.g., Mogil et al., 1996) and forced walking (e.g., Nakagawasai et al., 1999) as stressors, showed both an opioid-mediated and a nonopioid-mediated type of analgesia, depending largely on the intensity and duration of exercise.

A sixth theme relates to the psychoneuroendocrinology of exercise, particularly acute exercise. Discussing the results of one of the first studies in this area, Marianne Frankenhaeuser commented that "it appears likely that the adrenaline [i.e., epinephrine] increase was at least partly associated with the subjective emotional reaction accompanying heavy physical work, rather than being elicited by the work itself" (Frankenhaeuser et al., 1969, p. 348). Likewise, a few years later, John Mason wrote: "It appears that it may be very difficult experimentally to separate the role of psychological versus physiological stimuli to cortisol secretion during relatively severe or prolonged muscular exertion. . . . Subjective reactions at different levels of exercise should be carefully evaluated in future work in this field in an effort to separate hormonal responses to muscular work per se from attendant psychological reactions" (Mason et al., 1976, pp. 160-161). Although the objective of separating the contribution of "muscular work per se" and the "attendant psychological reactions" to the secretion of stress hormones during and following exercise remains elusive, several studies have examined these factors, producing correlational evidence of an association between hormonal responses and both perceptions of exertion (e.g., Skrinar, Ingram, & Pandolf, 1983) and affective responses to exercise (e.g., Perna et al., 1998; Rudolph & McAuley, 1998).

In addition to the six themes that we chose to highlight, the literature contains several other cases in which the study of exercise behavior and its effects has been served well by psychobiological approaches. These include, for example, studies on the effects of exercise training on personality and related hormonal indices (e.g., Ismail & Young, 1977; Sothmann, Ismail, & Chodepko-Zajiko, 1984); the interrelations between exercise, self-reports of stress and well-being, and immune parameters (e.g., La Perriere et al., 1990); the effects of acute and chronic exercise on sleep (e.g., Youngstedt, 2000); and the association between asymmetries in frontal hemispheric activity, assessed via EEG,

and affective responses to exercise (e.g., Petruzzello, Hall, & Ekkekakis, 2001). In the postgenomic era, it is also not surprising that one of the most prevalent and arguably most promising emerging trends is the appearance of the first animal (e.g., Rhodes, Garland, & Gammie, 2003) and human (e.g., Simonen et al., 2003) studies using methods of behavioral genetics to understand variations in exercise behavior.

Looking at the topics we have enumerated, one must reach the conclusion that psychobiology has had a meaningful impact on the efforts to better understand human behavior within sport and exercise settings. The breadth of scope and the diversity of topics are impressive and warrant considerable optimism for the future. To paraphrase Cacioppo and colleagues (2000), psychobiological research has provided insights into almost every facet of sport and exercise behavior. However, as we noted earlier, we see the potential as far greater.

The Present Volume

In an editorial in the *Journal of Sport and Exercise Psychology* in 2001, Steve Petruzzello wrote: "My sense is that we are at a crossroads as a field of inquiry. We can continue with our 'boxology' and draw boxes and arrows and ignore the body in which these boxes must reside. Or we can utilize the ever-expanding knowledge base, including the physiological along with the psychological and the social, and undoubtedly gain a far greater understanding of human behavior" (p. 266). We agree with this statement, and this volume is an effort to help further instigate and provide direction for integrative study. As we stated previously, we view the lack of education and the pervasive influence of dualistic thinking as the two primary hindrances to the integrative study of human behavior in the contexts of sport and exercise. The content of this volume was planned specifically with these two obstacles in mind.

First, we assembled a group of authors comprising some of the leading scholars from around the world who have developed truly integrative, systematic lines of inquiry into important aspects of the psychobiology of physical activity. These authors come from a variety of areas, including kinesiology, psychology, physiology, and neuroscience. But, despite this diversity, the common characteristic of the chapters in this book is that they represent exemplars of research that broke through the dualistic barrier by starting with a psychological or behavioral question and utilizing a psychobiological method or combination of methods to extend our understanding to a level otherwise unreachable. This is a particularly important point that we, as editors, hope will be abundantly clear in every chapter—utilizing the psychobiological approach is not scientism, science for the sake of science, but rather a way to understand a phenomenon more deeply or more fully than would be possible with a single level of analysis. Importantly, what we also hope will be evident is the absence of false dichotomies and dilemmas, pitting the body against the mind or psychobiological methods against the traditional "psychological" methods of behavioral observation and self-report. In fact, in many cases, readers will recognize excellent examples of multilevel analysis, in which the data gathered from the behavioral observation or the self-report inform and complement those gathered from the psychobiological method of inquiry and vice versa.

Second, we believe that a central mission of this volume is to help inspire and educate not only the next generation of exercise and sport psychobiologists but also the broader fields of exercise and sport psychology. Therefore, we instructed the authors to balance their desire to provide state of the science reviews in their areas of expertise with their role as educators. Specifically, we asked them to provide short descriptions of the methodologies involved in their research, from brain imaging to microdialysis to event-related potentials, and to organize their chapters in the following sections: (a) an introduction, outlining the relevance of the topic to the study of behavior in exercise and sport; (b) a description of the main questions addressed in the literature; (c) an identification of the limitations of the literature, both conceptual and methodological; and (d) directions for future investigations.

Arguably, a volume that does not have a unifying *thematic* focus such as motivation or anxiety or development, but is rather based on an epistemic philosophy and a diverse set of methodological approaches, may not be perfectly cohesive. Furthermore, as this volume could not encompass all areas of investigation, we made the decision to focus primarily, although not exclusively, on issues pertaining to exercise rather than sport performance, as this reflects the current balance in the research literature (a trend supported by the funding that is currently available for investigations targeting health and well-being).

The 17 chapters are organized in five sections, covering (a) foundational information on psychobiology, the brain, and the body (three chapters, including the present one), (b) the effects of exercise on cognition (two chapters), (c) the effects of exercise on emotion (four chapters), (d) the effects of exercise on psychosomatic health (five chapters), and (e) applications of psychobiology in human performance (three chapters). Finally, we offer some concluding comments and reflections in an epilogue.

In the two remaining chapters in this opening section, the authors open the "black box" to reveal the workings of the brain in response to exercise. **Bud Craig** describes what is presently known about the peripheral receptors, afferent spinal pathways, and brain centers that collect and process information about the physiological condition of the body. The information on the path that exercise-induced interoceptive cues follow as they ascend the levels of the neuraxis is usually scattered in journal sources from neuroanatomy and neurophysiology to neurology and has not been reviewed previously. This is also the first time that the coverage extends beyond the lower levels of the brain (such as the medulla), involved in basic life-preserving functions like cardiovascular regulation, to include areas relevant to cognition and emotion (such as the amygdala, the insula, the cingulate, and the prefrontal cortex). **Jon Williamson**'s chapter is also a "first"—it is the first to review imaging studies examining the patterns of activity in the human brain in response to exercise. The susceptibility of brain imaging technology to movement artifacts presents a persistent challenge that researchers are trying to address using various creative methodological approaches.

In the section on the effects of exercise on cognition, **Art Kramer** and **Chuck Hillman** review evidence, based on event-related potentials and brain imaging, in support of the selective beneficial effect of exercise on cognitive tasks that involve executive control. Their chapter places particular emphasis on the implications of this research for the prevention of cognitive decline in the elderly. **Henriette van Praag** focuses on basic research that addresses one of the possible reasons for the beneficial effects of exercise on cognitive performance. Specifically, she reviews the results of a series of animal studies demonstrating that wheel running is associated with neurogenesis, the development of new neurons, particularly in the hippocampus, an area of the brain involved in learning and memory. Importantly, the results, based on brain immunohistochemistry, are also accompanied by corroborating behavioral measures of learning.

In the section on the effects of exercise on emotion, **Michel Cabanac** discusses possible evolutionary explanations linking exercise to pleasure. The chapter also frames the hedonic responses to exercise within the context of consciousness and explains Cabanac's seminal idea of alliesthesia as it relates to sensations derived from exercise. **Panteleimon Ekkekakis** and **Ed Acevedo** examine new data on the dose–response relationship between the intensity of exercise and affective responses, with particular emphasis on the implications for the prescription of exercise and exercise adherence. **Steve Petruzzello, Panteleimon Ekkekakis,** and **Eric Hall** review theory-driven research connecting asymmetric patterns of electrocortical activity in the human brain, assessed through EEG, to affective responses to exercise. **Romain Meeusen** presents an overview of research on the effects of exercise training on brain neurotransmitters that are linked to depression and anxiety, including serotonin, norepinephrine, and dopamine. Of particular interest are the studies using microdialysis to study neurotransmitter changes in awake and moving animals.

In the section on the effects of exercise on psychosomatic health, **Mark Sothmann** presents the current evidence pertaining to the cross-stressor adaptation hypothesis. This hypothesis proposes that central and peripheral changes take place in response to exercise training, in both the cardiovascular and neuroendocrine systems and their central regulators, and that these changes then manifest themselves as an altered, more adaptive response to psychosocial or mental stress. **Steve Boutcher** and **Mark Hamer** focus specifically on exercise-induced adaptations in the cardiovascular system. This has been an area characterized by equivocal findings for decades. The authors attempt to resolve the controversy by presenting a multifactorial model of cardiovascular reactivity and delineating the individual-difference factors that may account for some of the variability in cardiovascular responses to stress and exercise adaptations. **Suzi Hong** and **Paul Mills** explore the fascinating area of psychoneuroimmunology, the interactions between exercise, stress, and the neuroendocrine and immune systems. **Greg Hand, Ken Phillips,** and **Marlene Wilson** present a chapter that exemplifies the shift from studying the peripheral manifestations of exercise-associated

changes in stress reactivity to studying the central regulatory mechanisms, including limbic and hypothalamic areas. **Dane Cook** presents a review of the complex relationship between exercise and pain, including a description of the neurobiology of pain and modulatory mechanisms.

In the section on applications of psychobiology in human performance, **Brad Hatfield, Amy Haufler,** and **Tom Spalding** provide a summary of over 20 years of research using a cognitive psychophysiology and neuroscience paradigm to understand the bases of superior sport performance. The concept of efficiency—the recruitment of the appropriate amount of cognitive resources for the effective execution of a task—is the central theme of their chapter. **Dave Collins** and **Alan McPherson** review what is presently known about the application of various modalities of biofeedback in the domain of sport. Given that this is a line of inquiry and application with a fairly long history in sport psychology, the chapter importantly and appropriately places emphasis on the limitations of many of the extant studies and proposes ways to overcome them. **Paul Holmes** reviews the research on the psychophysiology of imagery. He proposes a neuroscientific approach to the study of imagery in sport, combining the new information emerging from neuroscience on image generation with lessons from motor control.

As editors, we are delighted to have had this opportunity to serve the research community investigating the psychobiology of physical activity with the publication of this text. As we noted previously, for decades researchers have conducted investigations in psychobiology without a foundational text to facilitate this direction of inquiry. We hold two major visions for the impact of this text. First, we are optimistic that the leaders in the field, who built the foundation of psychobiological inquiry within the domain of physical activity, will view this text as the gratifying culmination of a long developmental phase. Second, we hope that students pursuing study in the fields of exercise and sport psychology, exercise science, psychology, neuroscience, physiology, and genetics will be intrigued and inspired by the cutting-edge research presented in this volume.

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PSYCHOBIOLOGY OF PHYSICAL ACTIVITY

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