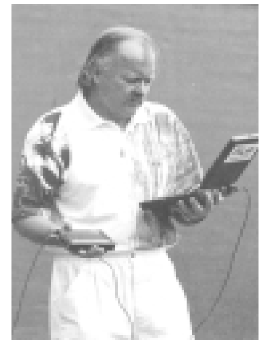
FEATURE ARTICLE



Ambulatory Psychophysiology and Ecological Validity in Studies of Sports Performance: Issues and Implications for Intervention Protocols in Biofeedback[i]

Roland A. Carlstedt, PhD, ABSP, New York, N.Y.

Abstract: *The heart activity of an elite tennis player was monitored over the course of two complete official tournament tennis matches to determine whether trends in heart rate deceleration observed in the laboratory and in more static sports would occur in an action sport. Consistent with previous research heart rate deceleration was evident prior to action phases of both matches. Greater magnitudes of heart rate deceleration also occurred in a match that was won compared to one that was lost. This study differed from previous ones in that heart activity was analyzed in the context of a realistic and more ecologically valid situation (entire real matches) and a meaningful longitudinal dependent measure of performance (match outcome).*

Since heart rate deceleration has been associated with attention, cognitive activity, and physiological reactivity, the author proposes that heart activity may be the measure of choice for assessing psychological and behavioral states in athletes and for concurrently validating or evaluating the efficacy of performance enhancement interventions including neurofeedback in real life competition, something that may be critical for the credibility and long-term viability of biofeedback in sport and performance psychology.

Ambulatory Psychophysiology

Ambulatory psychophysiology is the study and assessment of behavioral and physiological interactions in naturalistic settings (field research; Fahrenberg, 1996). Its methodology involves the continuous physiological monitoring (i.e., ambulatory monitoring) and observation of free-moving individuals in everyday life situations (Fahrenberg, 1996). Its application may be particularly important to the study of athletes and other performers (e.g., pilots, musicians, public speakers) where it is imperative that research findings and interventions have a high degree of ecological validity (i.e., the data must be procured from and reflect conditions encountered in context specific situations; Fahrenberg & Myrtek, 1996).

Although the value of ambulatory psychophysiological assessment has been recognized by sport and performance psychologists and coaches, it is a relatively unexplored and underused procedure despite the fact that many of the central constructs of sport and performance psychology including intensity are psychophysiologically based (Heil & Henschen, 1996; Taylor, 1996). For example, primary theoretical lines that elucidate the concept of intensity (reactivity) all have major physiological and psychophysiological components including Yerkes and Dodson' s (1908) Inverted-U, Hanin's (1980) Zone of Optimal Functioning (ZOF), and Hardy and Fazey's (1987) Catastrophe theories.

Unfortunately, these and numerous other concepts and interventions in sport and performance psychology have not been sufficiently researched especially at the intra-individual level and temporally. Essentially, little is known about the underlying psychophysiology these theories allude to or bodily changes mental training methods supposedly induce. Taylor's (1996) view of intensity (reactivity/activation), which he refers to as:

> the most critical factor prior to competitive performance because, no matter how confident, motivated, or technically or physically prepared athletes are to perform, they will simply not be able to perform their best if their bodies are not at an optimal level of intensity, accompanied by the requisite physiological and psychological changes... (p. 75)

illustrates the imprecise manner in which physiology and interventions in sport and performance psychology are often discussed. In analyzing Taylor's perspective on intensity, one still must ask, what do "confident " and "motivated " mean? Also, what is an "optimal level of intensity," and what are "requisite physiological" and psychological changes" that accompany intensity? Similarly, how do sport psychology practitioners know they are really entraining "heightened attention" or manipulating reactivity (intensity) when using biofeedback since these psychophysiological states have yet to be adequately delineated or operationalized during real sport competition or unequivocally associated with potent outcome measures (i.e., dependent or criterion variables). Without studying the components and effects of physiological and psychophysiological processes on "real life"performance assumptions about intensity or states of activation and the effects of interventions on athletes remain speculative.

In my Master's thesis (Carlstedt, 1998) I wanted to address some of the above issues and the concept of ecological validity by investigating sport performance in the context of an entire "official" competition (in contrast to doing so in a contrived or practice situation), to better delineate psychophysiological parameters and performance relationships in a realistic setting. My ultimate goal was to establish and/or describe psychophysiological and performance relationships having a higher degree of ecological validity than observed in previous research in sport, including that demonstrated by most neurofeedback[1] intervention protocols and research paradigms used in sport today. Doing so is a necessary (but often overlooked) first step in validating and determining the reliability of interventions in sport and performance psychology.

Heart Rate Deceleration Revisited: An Ideal Measure of Psychological Performance

To pursue this goal I settled on heart activity during tennis tournament competition as the focus of a preliminary study, a surprisingly sparingly used measure considering the large body of evidence associating specific parameters of heart activity with psychological factors thought important to sport performance, and since it is probably the only physiological measure that can be obtained relatively non-invasively during the course of an entire real sport competition.

In addition to reflecting emotions and other psychological states (e.g., motivation, intensity), heart activity has been found to be an important measure of attention and cognitive activity (Sandman, Walker & Berka, 1982), factors that are thought to affect sport performance (Carlstedt, 1998, 2001). In reviewing the literature, Sandman, et al. (1982) concluded that HR and blood pressure (BP) differentiated cognitive-perceptual processes better than EEG. Galin (1974) also suggested that heart activity is more useful than EEG for analyzing attentional processes, because EEG only represents activity at the dorsal convexity of the brain but does not reflect activity in deep medial brain areas such as the hippocampus and the amygdala. Pribram and McGuiness (1975) have shown that the hippocampus and amygdala play an important role in attentional processes.

Experimental evidence also indicates significant interactions between the cardiovascular, the central nervous, and the somatic systems (Andreassi, 1995). One line of research has established relationships between cardiac activity and reaction time (RT), with Lacey and Lacey (1964) reporting decreased heart rate (i.e., heart rate deceleration; HRD) during the fixed foreperiod of simple RT experiments. It has also been shown that greater magnitude of heart rate (HR) slowing is related to faster RTs (Lacey, 1967). It has been suggested that HRD represents a preparation to respond when an individual expects a significant stimulus (Andreassi, 1995). Fast reactions are also associated with peak sport performance (Carlstedt, 1995).

Investigations in sport have also documented HRD. In a comparison of elite and beginning golfers during putting, Boutcher and Zinsser (1990) reported more HRD in better golfers. In another study, Hatfield, Landers, and Ray (1984) reported elite rifle shooters exhibited HRD prior to shooting, providing evidence in support of previous electrophysiological and neurocardiologic explanations of psychologically mediated HRD (e.g., Lacey & Lacey, 1978; Sandman et al. 1982). For example, it was found that increased right hemispheric EEG activity was a concomitant of HRD prior to shooting and that elite marksmen appeared capable of attending to the extent that they could unconsciously reduce cognitive activity in the left hemisphere prior to action. Left hemisphere cognitive activity has been associated with the disruption of motor performance (Hatfield et al.,1984; Langer & Imber, 1979).

The above studies are important because they have clearly established that the magnitude of HRD during self-paced sports was associated with a performer's level of skill and state of attention. In addition, Hatfield et al.'s (1984) study suggests that even if heart activity measures are used in place of EEG, information on attentional states and reactivity can still be inferred.

However, these studies like most psychophysiological investigations in sport did not analyze within-subject differences in a physiological measure (e.g., HRD) as a function of performance during real competition and in relationship to meaningful longitudinal operationalizations of outcome (e.g., match outcome on separate days). Hence, another purpose of my study was to attempt to fill some of the gaps in the literature of sport psychophysiology.

Hypotheses

To test whether HRD patterns during tennis matches would resemble decelerative trends observed in previous research I used ambulatory heart monitoring equipment to measure a tennis player's heart activity over the course of two entire official tournament tennis matches (Match 1 and 3). I hypothesized that heart inter-beat-intervals (IBI) would progressively lengthen (i.e., HR would become slower) prior to action (when waiting to return a serve). I also predicted that greater magnitude of HRD in pre-action phases of matches would occur with successful compared to unsuccessful performance (winning versus losing a match).

Results

Match Outcome

Match 1 was won by a score of 6-4, 6-1. Match 3 was lost 6-0, 6-1 (the score of match 3 is the second worst score possible in a best of three set match).

HRD Phases

There were 51 pre-action phases in

[1] Although neurofeedback is rapidly becoming the modality of choice in attempting to entrain attention, the invasive nature.and artifact proneness of EEG makes it difficult to use reliably during action sports. By invasive I mean EEG equipment and monitoring procedures today limit and disrupt an athlete's movement during competition. By contrast, Holter and HR telemetry equipment and the Polar system (used in this study) can be worn with minimal discomfort and virtually no constraints on movement throughout the course of an action sport. Moreover, most data derived from EEG/neurofeedback studies emanate from laboratory or contrived paradigms, with no studies having demonstrated supposed ideal EEG activity (ideal states of attention) during real competition, calling into question the ecological validity of many current neurofeedback protocols and EEG research paradigms.

Match 1 and 27 in Match 3. Pre-action phases were identified using videotapes of the matches. These phases corresponded with heart activity recordings extracted from the data readouts. In Match 1 there were 283 decelerating IBIs prior to the 51 action phases, or a mean of 5.55 IBIs per pre-action phase. There were 112 decelerating IBIs prior to 27 action phases in Match 3, or a mean of 4.15 IBIs per pre-action phase.

An examination of all pre-action IBIs in Match 1 and Match 3 revealed HRD in all IBIs prior to action. The presence of HRD in IBIs prior to action confirmed the hypothesis that HRD trends during tournament tennis would resemble decelerative trends observed in previous laboratory and field studies

R   R   Response-Service Return>>>>>>Action>>><HRD<
I__I__I__I___I____I______I_____I__I__I_I_I_I_I_I__I___I
pre-action heart rate deceleration<<<<<I>>>>>>>>>>>>>I<<< HRD

Figure 1. Sample selection of pre-action, action, and post-action IBIs in Match 1. Notice that the IBIs become progressively longer leading up the response IBI. Thereafter the IBIs become progressively shorter during the action phase. After action ceases the IBIs again become longer in the post-action recovery phase. Longer IBIs indicate a slowing of the heart. Shorter IBIs indicate an acceleration of the heart or a shorter and faster heart period.

The following IBI combinations were also examined to determine if greater magnitude of HRD would be evident in a match that was won compared to a match that was lost: 1) the difference in the rate of HRD between all IBIs prior to action in Match 1 compared to Match 3; and 2) the difference in the rate of HRD between the last IBI prior to action in Match 1 and Match 3.

Findings included: 1) total IBIs prior to action in Match 1 compared to Match 3 revealed more pre-action HRD in Match 1 than in Match 3.

Match 1
R............................6.79msec............................R
I____I

Match 3
R................5.57msec................R
I___________________________I

Figure 2. Mean rate of heart rate deceleration for all IBIs prior to action in Match 1 compared to Match 3 (p = .045).

2) The last IBI prior to action compared to the next to last IBI was longer (slower) in Match 1 but not in Match 3.

Match 1
R...............6.37msec........R..................11.67sec................................R
I______________________I_____________________________________I
Next to last IBI prior to action   Last IBI prior to action

Match 3
R..........5.42 msec....R.......................8.67msec.......R
I__________________I_________________________I
Next to last IBI prior to action   Last IBI prior to action

Figure 3. Mean difference in heart rate deceleration between the last IBI prior to action compared to the next-to-last IBI in Match 1 (p < .008) and mean difference of the rate of heart rate deceleration between the last IBI prior to action compared to the next-to-last IBI in match 3 (p < .079).

Discussion

The results of my study showed that HRD preceded action phases during both tennis matches. More importantly, the general hypothesis of the study, which predicted more HRD prior to action phases in a match that was won compared to a match that was lost, was confirmed. Although both matches were marked by progressive HRD leading up to action, Match 1 showed greater HRD in all configurations of IBIs prior to action. A particularly noteworthy finding was that the last IBI prior to action was longer compared to the preceding IBI (i.e., exhibited more HRD) in Match 1 than Match 3. This finding is consistent with studies by Lacey & Lacey (1978) and Jennings & Woods (1977), which reported the greatest amount of HRD in the last IBI prior to the presentation of a stimulus (e.g., the serve in tennis). These data also replicated studies reporting that successive IBIs, prior to the imperative stimulus, become progressively slower as the time of response nears (Jennings & Wood, 1977; Lacey & Lacey, 1978).

It should be noted that HRD occurred both within matches and between matches with this study also showing for the first time statistically significant within-subject differences between HRD and performance and a longitudinal measure of outcome (matches on different days).

This study also marked the first time that HRD has been demonstrated at higher HR levels. In previous research, HRD was observed in the 70-90 beats per minute (bpm) range, whereas in this study, HRD occurred at levels as high as 150 bpm (Boutcher & Zinsser,1990). This is noteworthy, as experiments of operant conditioning of HR (McCanne & Sandman, 1976) have only attempted to slow HR below resting baseline or slightly elevated HR and has implications for biofeedback, suggesting that athletes can be conditioned to induce HRD even at high heart rates (important in basketball prior to the free throw or after a long rally in tennis).

The results of my study become more meaningful when considering the diametrically opposite performance and outcome of the two matches. These extreme differences are reflected in quantitative performance data (e.g., match score and statistics) and qualitative impressions of the match (i.e., psychological performance). In addition, the player's self-report indicated major differences in attention, emotions, self-confidence, cognitive activity, and reactivity between matches, feedback that was consistent with HRD trends and in line with theoretical and hypothetical explanations of what HRD is thought to reflect (increased attention and reduced cognitive activity, and reactivity).

The fact that performance and outcome between-matches were incongruous suggests that HRD is not only a species-wide physiological response to an impending stimulus, but that HRD appears to vary as a function of specific tasks, performance demands, and psychological factors and may be a global longitudinal marker of differential states of attention, reactivity, and cognitive activity during real competition.

Implications and Issues

Since the ability to use of EEG and other physiological measures in studying athletes in realistic situations is quite limited, researchers and practitioners should consider using heart activity to describe and assess psychological and behavioral states and the efficacy of interventions to manipulate these states during competition. In addition to generating unique information on attention, cognition, and reactivity, heart activity could be used to validate concurrently theories and hypotheses in neurofeedback that have yet to substantiated. For example, after a neurofeedback session an athlete's heart activity could be monitored during actual competition to determine whether behavior or responding that has supposedly been entrained through neurofeedback corresponds with an empirically demonstrated measure of attention, cognitive activity, and reactivity; namely, heart rate deceleration. As previously mentioned, Hatfield et al.'s (1984) study suggests this should be possible.

If entrainment has been successful one would expect HRD trends to reflect such. Rather than relying on self-report and weak dependent outcome or performance measures, practitioners and researchers should actively attempt to validate many of the claims associated with neurofeedback (in sport) in the context of a new and more ecologically valid paradigm, using a concurrent physiological measure (heart activity) known to reflect those psychological states neurofeedback attempts to manipulate to enhance the performance of athletes.

The reliability and credibility of biofeedback protocols ultimately depends on the ecological validity of the data used to conceive of methods such as neurofeedback in sport. Researchers, practitioners, coaches and athletes must be certain target levels of activity being entrained (e.g., specific levels of EEG activity) indeed occur during temporally isolated moments of competition (e.g., prior to a critical moment like a break-point in tennis or crucial putt in golf). Not only should specifically entrained physiological activity be apparent during important competitive moments, it also must be associated with improved performance when manifested (i.e., a specific range of EEG activity must be associated with a meaningful dependent measure of better performance such as sinking a crucial putt in golf).

I predict that the future of biofeedback and neurofeedback in sport and performance psychology will depend on our ability to accurately delineate psychophysiological activity during real competition and thereby discern whether attempts to entrain specific responding indeed has an effect on sport performance. To date our best hope for achieving this may lie with heart activity. Heart activity is a physiological measure that is backed by a significant body of empirical research that has isolated parameters of ideal responding that appear to reflect attention, cognitive activity, and reactivity, during real sport competition, something that has not been evidenced using other physiological systems and modalities including neurofeedback.

Although using heart activity requires much work in the initial phases of research and practice it is probably the only measure allowing for the continuos physiological monitoring of athletes in real competition and should be considered by all practitioners in sport psychophysiology and biofeedback as an alternative or adjunct to EEG and other modalities that are restricted in their scope of usage.

Limitations and Future Directions

These preliminary findings were consistent with previous research of HRD in the laboratory and static sports. Future studies should attempt to replicate these results on a larger scale and in a variety of action sports in hopes of unequivocally establishing HRD as an important component of the performance equation and heart activity as an ideal psychophysiological measure of various performance parameters during real sport competition.

References

Andreassi, J.L. (1995). *Psychophysiology: Human behavior and physiological response* (3rd ed.). Hillsdale, NJ: Erlbaum.

Boutcher, S. H., & Zinsser, N. W. (1990). Cardiac deceleration of elite and beginninggolfers during putting. *Journal of Sport and Exercise Psychology*, 12, 37-47.

Carlstedt, R.A.(1995). Mentales tennis. Munich, Germany: SportInform Verlag.

Carlstedt, R. A. (1998). *Psychologically mediated heart rate variability: A single case study of heart rate deceleration and a spectrum analysis of autonomic function during tournament tennis.* Unpublished Master's thesis. San Francisco: Saybrook Graduate School

Carlstedt, R. A. (2001). *Line bisecting test reveals relative left brain hemispheric predominance in highly skilled athletes: Relationships among cerebral laterality, personality, and sport performance.* Unpublished Doctoral Dissertation. San Francisco: Saybrook Graduate School.

Fahrenberg, J. (1996). Concurrent assessment of blood pressure, heart rate,physical activity and emotional state in natural settings. In J. Fahrenberg & M. Myrtek (Eds.) *Ambulatory psychophysiology: computer assisted psychological and psychophysiological methods in monitoring and field studies* (pp. 165-188).Goettingen, Germany: Hogrefe & Huber.

Fahrenberg J. & Myrtek, M. (1996). *Ambulatory psychophysiology: computer assistedpsychological and psychophysiological methods in monitoring and field studies.* Goettingen, Germany: Hogrefe & Huber.

Galin, D. (1974). Implications for psychiatry of left and right cerebral specialization. *Archives of General Psychiatry,* 31, 572-581.

Hanin, Y. L. (1980). A study of anxiety in sports. In W. F. Straub (Ed.), Sport psychology : An analysis of athletic behavior (pp. 81-106). Chichester, United Kingdom: Wiley.

Hardy, L., & Fazey, J. (1987). *The inverted-U hypothesis: A catastrophe for sport psychology.* Paper presented at the annual meetings of the North American Society of Sport and Physical Activity, Vancover, British Columbia, Canada.

Hatfield, B. D., Landers, D. L., & Ray, W. J. (1984). Cognitive processes during self-paced motor performance: An electroencephalographic profile of skilled marksman. *Journal of Sport Psychology*, 6, 42-59.

Heil, J., & Henschen, K. (1996). Assessment in sport and exercise psychology. In J. L. Van Raalte & B. W. Brewer (Eds.), *Exploring sport and exercise psychology* (pp. 229-256). Washington, D.C: American Psychological Association.

Jennings, J. R., & Wood, C. C. (1977). Cardiac cycle time effects on performance, phasic cardiac responses, and their intercorrelation in cardiac reaction time. *Psychophysiology,* 14(3), 297-307.

Lacey, J. I., (1967). Somatic response patterning and stress: Some revisions of activation theory. In M. H. Appley & R. Trumbell (Eds.), *Psychological stress: Issues in research* (pp 14-42). New York: Appleton-Century-Crofts.

Lacey, J. I., & Lacey, B. C. (1964). *Cardiac deceleration and simple visual reaction in a fixed foreperiod experiment.* Paper presented at the meeting of the Society for Psychophysiological Research, Washington, D.C.

Lacey, J. I., & Lacey, B. C. (1978). Two-way communication between the heart and the brain: Significance of time within the cardiac cycle. *American Psychologist,* 33(2), 99-113.

Langer, E., & Imber, L. G. (1979). When practice makes imperfect: Debilitating effects of overlearning. *Journal of Personality and Social Psychology,* 37, 2014-2024.

McCanne, T. R., & Sandman, C. A. (1976). Human operant heart rate conditioning: The importance of individual differences. *Psychological Bulletin,* 83, 587-601.

Pribam, K. H., & McGuinness, D. (1975). Arousal, activation, and effort in the control of attention. *Psychological Review*, 82, 116-149.

Sandman, C. A., Walker, B. B., & Berka, C. (1982). Influence of afferent cardiovascular feedback on behavior and the cortical evoked potential. In J. T. Cacioppo and R. E. Petty (Eds.), *Perspectives in cardiovascular psychophysiology* (pp. 189-222). New York: Guilford.

Taylor, J. (1996). Intensity regulation and athletic performance. In J. L. Van Raalte and B. W. Brewer (Eds.). *Exploring sport and exercise psychology,* (pp. 75-106). Washington D.C: American Psychological Association.

Yerkes, R. M., & Dodson, J. D. (1908). The relation of strength of stimulus to rapidity of habit formation. *Journal of Comparative Neurology and Psychology*, 18, 459-482.

[i] This article is based in part on my Master's thesis at Saybrook Graduate School in San Francisco. Special thanks go out to my Master's thesis chair Dr. Eugene Taylor of Saybrook and Harvard Medical School and committee member Dr. Arne Collen of Saybrook. Correspondence: via www.americanboardofsportpsychology or DrRCarlstedt@aol.com.