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Heart Rate Recovery Kinetics Following Submaximal Treadmill Exercise in Male University-Level Badminton Players: Implications for Cardiovascular Fitness and Athletic Recovery

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ABSTRACT:

Background: Heart rate recovery (HRR) is a recognized non-invasive test of cardiovascular fitness and autonomic nervous system function. Rapid parasympathetic nervous system reactivation is indicated by a quick recovery of heart rate after exercise (HRR). Higher aerobic fitness, improved recuperation, and a decreased risk of cardiovascular disease have all been associated with it. Although HRR has been extensively studied in endurance athletes, there is little data on recovery kinetics in university-level badminton players, a sport that requires repeated high-intensity intermittent efforts using both anaerobic and aerobic energy systems. **Objectives:** The goal of this study was to evaluate male university badminton players' post-exercise heart rate recovery patterns following a standardized submaximal treadmill exercise regimen. **Methods:** Twelve (n=12) male university badminton players from Jashore University of Science and Technology's Department of Physical Education and Sports Science participated in a descriptive repeated measures study. Participants performed a standardized 5-minute submaximal run on a treadmill following a formal warm-up. A heart rate monitor with a chest strap was used to continually record the heart rate. Recovery heart rate was measured every 30 seconds during a 5-minute passive recovery phase and right after exercise (0 s). Descriptive statistics (means and standard deviations) were used to summarize heart rate responses during recovery. **Result:** Following the exercise, the heart rate was 167.75 ± 10.45 bpm. It dropped to 135.92 ± 6.83 bpm after 30 seconds and 111.33 ± 9.81 bpm after 90 seconds. The heart rate dropped to 92.00 ± 7.70 bpm after the five-minute rest time. The first ninety seconds of recovery saw the biggest drop-in heart rate; after that, the decline was more steady and nearly linear. These findings suggest a constant autonomic stability and a rapid parasympathetic reactivation during the early stages of recovery. **Conclusion:** Male university badminton players' heart rates recovered quickly in the first ninety seconds following submaximal activity, indicating strong autonomic control and cardiovascular recuperation. The observed recovery kinetics imply that HRR is a straightforward and non-invasive indicator to track badminton players' training adaptation and cardiovascular fitness. To validate the results and create sport-specific normative norms, more research with a bigger sample size, female athletes, and sophisticated statistical analysis is advised.

1. INTRODUCTION:

Badminton is one of the fastest racquet sports in the world and players have to attend regular high intensity training sessions with short break intervals. During the competition, the athletes have to make explosive accelerations, rapid changes of direction, jump, lunge, and strike above the head, which puts a tremendous load on the anaerobic and aerobic energy systems (Phomsoupha & Laffaye, 2015). Rallies are normally short but consist of multiple high intensity bouts of work and therefore require efficient cardiovascular function and rapid physiological recovery to maintain performance and delay fatigue (Faude et al., 2007). During exercise the circulatory system is important in the removal of metabolic waste products and in giving oxygen and nutrition to the skeletal muscles being exercised. Therefore, cardiovascular fitness is viewed as an important factor for athletic performance in general, especially in intermittent sports such as badminton. Traditionally, cardiovascular fitness has been measured by measurements such as maximum oxygen consumption (VO2 max), resting heart rate, stroke volume, cardiac output, blood pressure, and exercise capacity (Powers & Howley, 2021). Although these markers provide significant information regarding cardiovascular function, the frequent use of many of them in athletic settings is limited by the need for skilled personnel and advanced laboratory equipment. Heart rate recovery (HRR) is a simple, inexpensive and non-invasive indicator of cardiovascular fitness and autonomic nervous system function. The HRR is the rate of heart rate fall immediately after exercise cessation (Cole et al. 1999; Pierpont and Voth 2004). It is essentially a sign of parasympathetic re-activation and the slow tapering off of sympathetic activity. A delayed HRR has been linked to poor autonomic function and increased risk of cardiovascular disease and mortality (Cole et al., 1999; Shetler et al., 2001) whereas a rapid decline in heart rate in the first few minutes after exercise is generally thought to reflect better autonomic control, improved cardiovascular fitness and better recovery (Cole et al., 1999; Shetler et al., 2001). The HRR is controlled by the complex interplay of the sympathetic and parasympathetic branches of the autonomic nervous system. The sympathetic activation during exercise increases heart rate and cardiac output to meet the increased metabolic needs of working muscles. After exercise, sympathetic activity gradually decreases until resting cardiovascular equilibrium is reached and parasympathetic reactivation quickly lowers heart rate (Arai et al., 1989). Previous investigations revealed that vagal reactivation is restricted in the first 60s to 90s of recovery and the later phase of recovery is characterized by parasympathetic activity, sympathetic withdrawal, thermoregulatory reactions and metabolic recovery (Buchheit & Gindre, 2006). HRR is increasingly used in sports sciences as an objective marker of an athlete's readiness, fatigue and training adaptation capability. Repeated reports in the literature have shown a faster HRR in highly trained athletes compared with recreationally active persons indicating a higher autonomic control and cardiovascular efficiency (Daanen et al. 2012). Consequently, HRR assessments are being widely used by coaches and sports scientists to assess training responses, optimize recovery strategies, monitor overtraining and guide return-to-play decisions following illness or injury. Badminton has specific physiological demands due of frequent transitions between high intensity anaerobic activities and low intensity aerobic recovery periods. Previous studies have shown that aerobic metabolism contributes 60-70% of the energy utilized during a badminton game and the remaining during explosive movements by anaerobic metabolism (Phomsoupha & Laffaye, 2015). The diverse energy profile stresses the need for a rapid circulatory recovery between rallies and throughout play. Therefore, HRR characteristics can give vital insight into an athlete's training status, competitive performance and physiological preparation. The HRR is widely used in numerous sports although the recovery kinetics of university level badminton players in particular in South Asian populations is not well recognized. There is little information available on collegiate badminton players. Most published research has focused on endurance athletes, soccer players, or the general physically active population. Sport specific HRR profiles can be used by coaches to assess cardiovascular reactions, prescribe conditioning programs, and track recovery throughout practice and competition. In this context the present study was undertaken to evaluate the heart rate recovery pattern of male university level badminton players after a standardized submaximal treadmill workout regimen. The goal of this study was to investigate heart rate variability in the first 5 min of passive recovery following exercise. heart rate was expected to decrease rapidly for the first ninety seconds of recovery and then gradually return to resting levels.

The results of the present study may not only provide useful information to coaches, sports scientists and exercise professionals involved in monitoring and optimizing athletes' performance but also contribute to the knowledge of the autonomic recovery dynamics of badminton players.

2. MATERIAL AND METHODS:

2.1. Design of study:

The present study utilized a descriptive observational design with repeated measures to examine the pattern of heart rate recovery (HRR) following submaximal exercise in male university badminton players. Heart rate was recorded continuously for 5 minutes of passive recovery and immediately post exercise at 30 second intervals. The repeated-measures design enabled us to assess the change in heart rate over time in the same subjects without any intervention.

2.2 Teilnehmer:

Twelve (n=12) male collegiate badminton players volunteered to take part in the study. All participants were the members of the badminton team of the Department of Physical Education and Sports Science, Jashore University of Science and Technology (JUST), Bangladesh. Prior to participation, each participant was informed of the aims, methods, possible risks and benefits of the study and signed informed consent was obtained. "Participation was entirely voluntary – participants were free to withdraw from the research at any time with no consequences.

2.3. Inclusion Criteria:

To qualify for the study, participants had to meet each of the following requirements: Men badminton players aged 18-30. Jashore University of Science and Technology Badminton players are active. regular practice of badminton and at least one year experience in playing. The participant is apparently healthy according to the pre-participation health questionnaire. There are no known conditions affecting the neurological, musculoskeletal, respiratory, metabolic or cardiovascular systems. Avoid use of drugs with known effects on cardiovascular function and/or heart rate . able and willing to sign an informed consent willing to comply with all study protocols.

2.4 Exclusion criterions:

Individuals with any of the following conditions were excluded from participation: previous medical history of asthma, diabetes mellitus, hypertension, heart disease or other long-term systemic conditions. • Any disease or injury of your musculoskeletal system that may limit your ability to exercise. Use of beta-blockers and other drugs that alter heart rate. Consumption of alcohol, coffee, nicotine or other stimulants within 24 hours prior to the test. strenuous exercise in the 24 hours prior to data collection. did not complete the recovery measurements and exercise program. Informed consent may be withdrawn at any time during the trial.

2.5 Ethical considerations:

The study was conducted in accordance with the ethical standards of the declaration of Helsinki for research on human subjects. A written informed consent form was signed by each participant before data collection. To protect their privacy and anonymity, each participant was assigned a unique identifying code throughout the study. Every piece of information gathered was used for study alone.

3. RESULT:

3.1. Sample Characteristics:

The study involved twelve (n=12) male university level badminton players. All subjects successfully completed the submaximal treadmill training program and no adverse events were reported during data collection. HRR values were taken successfully at 30 second intervals for five minutes immediately after exercise.

3.2 Heart Rate Recovery Following Submaximal Exercise:

Table 1 presents descriptive HR statistics for the recovery phase. Immediately after exercise, resting heart rate was 167.75±10.45 (0 s). The average heart rate was significantly lower at 30 s (135.92 ± 6.83 bpm) and 60 s (119.00 ± 9.18 bpm) throughout the first minute of recovery.

Pulse rate was much lower in the first 90 seconds (111.33 ± 9.81 bpm). Then the heart rate declined at an even slower rate, to 92.00 ± 7.70 bpm at the end of five min rest period.

These data show a fast autonomic recovery after exercise and a sluggish stabilization of cardiovascular function.

Table 1. Heart Rate Recovery Following Submaximal Exercise (n = 12)

Recovery Time	Mean Heart Rate (bpm)	Standard Deviation
(0 s)	167.75	10.45
30 s	135.92	6.83
60 s	119.00	9.18
90 s	111.33	9.81
120 s	106.25	8.90
150 s	103.25	6.78
180 s	98.83	6.46
210 s	96.92	7.83
240 s	94.92	5.81
270 s	94.50	7.03
300 s	92.00	7.70

3.3 Percentage Reduction in Heart Rate During Recovery

To better illustrate cardiovascular recovery, the percentage reduction in heart rate from the immediate post-exercise value was calculated (Table 2).

Table 2. Percentage Reduction in Heart Rate During Recovery

Recovery Time	Mean HR (bpm)	Reduction from Peak (bpm)	Percentage Reduction (%)
0 s	167.75	0.00	0.0
30 s	135.92	31.83	18.97
60 s	119.00	48.75	29.06
90 s	111.33	56.42	33.63
120 s	106.25	61.50	36.65
150 s	103.25	64.50	38.45
180 s	98.83	68.92	41.08
210 s	96.92	70.83	42.22
240 s	94.92	72.83	43.42
270 s	94.50	73.25	43.65
300 s	92.00	75.75	45.16

3.4 Trend of Heart Rate Recovery

Figure-1
Submaximal-load treadmill running and
Post-exercise recovery phase data collection

Heart rate recovery over time is shown in Fig. 1. Heart rate fell markedly in the first recovery phase (0-90 s), suggesting quick parasympathetic reactivation shortly after exercise. The recovery curve was progressively flatter after 90 s with a slower return of HR to resting levels.

The recovery profile was biphasic:
The heart rate drops fast. Phase I 0-90 seconds
Phase II (90-300 seconds) Heart rate decreases slowly and almost linearly.
Such a biphasic reaction is characteristic of normal autonomic recovery after submaximal exercise .

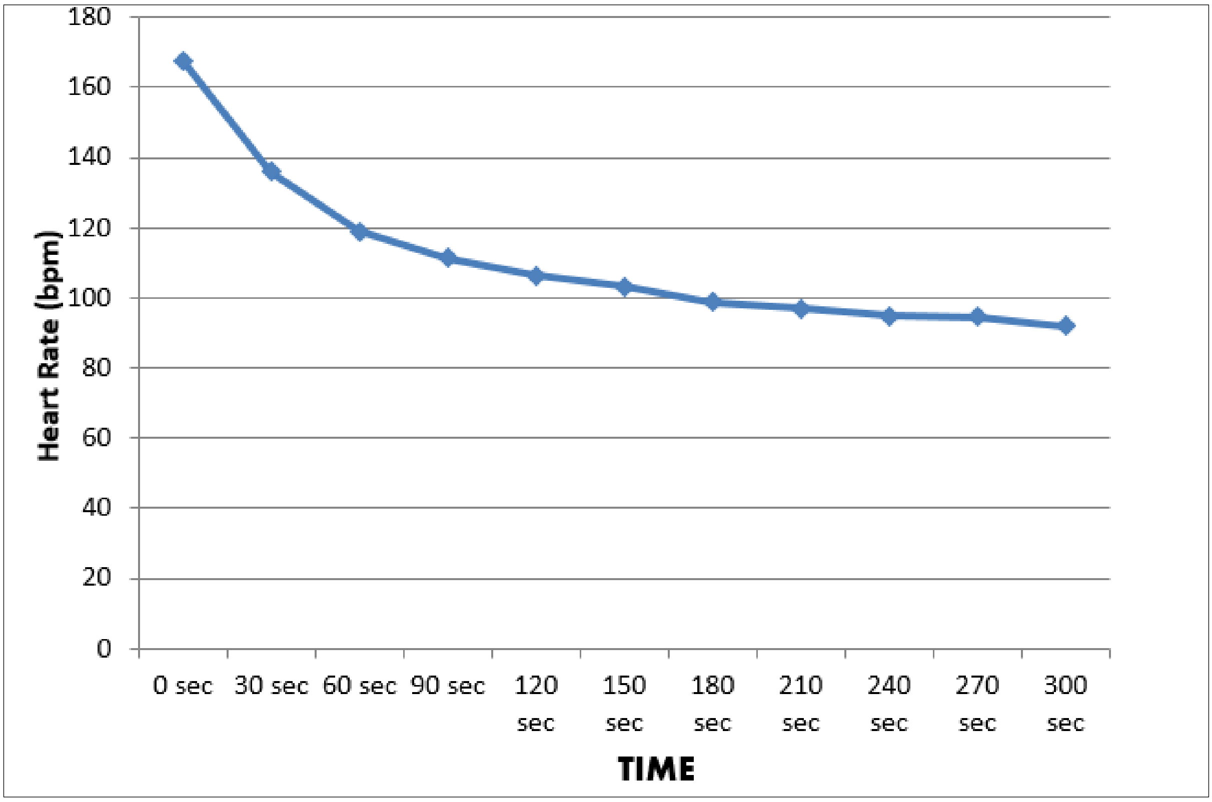

Figure 2. Heart Rate Recovery Curve Following Submaximal Exercise

From Figure -2 it is also known that the decrease of heart rate was more rapid for first 90seconds and thereafter it tends to decline in a relatively linear manner.
X-axis: Time to recovery (seconds)
Heart Rate (beats·min-1)
Data points 0 Average heart rate at each recovery interval
Error bars: SD
Line: Associated with circles
Fig. 2: Mean Heart Rate Response of Male University Badminton Players During 5 Min Recovery After Submaximal Treadmill Exercise The first ninety seconds was a steep drop and then a slow decline until the recovery time was over.

3.5 Summary of Findings
Below is a summary of the main results of this work:
The average heart rate after exercise was 167.75 +/- 10.45 beats per minute.
The greatest decrease in heart rate occurred in the first ninety seconds of recovery.
Heart rate decreased approximately 45.2% in the five minute recovery period.
Heart rate first decreased rapidly, and then slowly, almost linearly, increased.
The recovery kinetics in male collegiate badminton players shows good autonomic modulation and favorable cardiovascular recovery.

DISCUSSION:

The current study evaluated the heart rate recovery (HRR) pattern of male university level badminton players following 5 minutes of submaximal treadmill training. The key finding of this study was that HR dropped fast in the first ninety seconds of recovery and thereafter reduced gradually and slowly. In particular, mean heart rate was dropped from 167.75 ± 10.45 bpm at the end of the activity to 111.33 ± 9.81 bpm in the first 90 seconds and 92.00 ± 7.70 bpm during the 5-min rest. These results indicate a good cardiovascular fitness and autonomic recovery in the badminton players involved in this study.

The heart rate recovery (HRR) is an important physiological index of cardiovascular health and exercise adaptation, which is predominantly mediated by the autonomic nervous system (Cole et al., 1999). The substantial reduction in heart rate is attributed to a quick parasympathetic (vagal) reactivation shortly after the cessation of exercise and a sympathetic withdrawal that gradually contributes to the later phases of recovery (Arai et al., 1989). The quick fall observed in the first 90 s of the present investigation most likely reflects the phenomena of effective parasympathetic reactivation in trained athletes with exceptional cardiovascular fitness.

These results are consistent with Cole et al. (1999) who found that faster heart rate recovery after exercise is related with greater autonomic function and lower risk of cardiovascular disease. Their groundbreaking work established that HRR is a simple and clinically relevant marker of cardiovascular health. Furthermore, HRR has been found to be beneficial in the measurement of cardiovascular fitness in athletes and healthy patients and to provide useful information on the activity of the autonomic nervous system (Pierpont and Voth, 2004). The present study reaffirms previous findings and shows that university level badminton players have good autonomic modulation during submaximal exertion.

Similarly, the physiological model described by Buchheit and Gindre (2006) is in line with the biphasic recovery pattern seen in the present investigation. The scientists found that heart rate recovers in two stages. The initial 1–2 min following exercise cessation are dominated by parasympathetic reactivation, whereas the ensuing phase is characterized by sympathetic withdrawal and continuing metabolic recovery. This well-known physiological pattern is similar to the recovery profile in the present experiment, which displays a fast initial decline followed by a gradual decline.

In badminton, players are required to undertake repeated high energy activities (accelerations, decelerations, hops, lunges and direction changes) with brief rest intervals. Hence, in terms of cardiovascular capacity, the ability to recover fast between rallies is equally vital for performance success as technical and tactical skills (Phomsoupha & Laffaye, 2015). Therefore, the lower HRR in the present study may be attributed to the long-term cardiovascular adaptation to regular badminton training such as increase in stroke volume, enhanced autonomic regulation, and improvement in aerobic capacity.

In a previous study comparing trained and untrained subjects, athletes showed faster HR recovery after exercise due to improved cardiovascular efficiency and autonomic adaptations. Jennifer et al. (2018) showed that HRR was considerably faster in trained than untrained people suggesting beneficial effects of regular physical activity on autonomic recovery. Similar to this, HRR was proposed by Daanen et al. (2012) as a valuable indication to assess training status, tiredness and exercise adaptation of athletes. The recent findings provide more support for the use of HRR as a beneficial monitoring tool for the college badminton players.

Heart rate rapid reduction during early recovery phase could possibly be a sign for increased vagal tone after long-term sports involvement. Intermittent high intensity exercise and endurance training have been demonstrated to boost parasympathetic activity and decrease resting sympathetic impact resulting in a speedier cardiovascular recovery post exercise (Powers & Howley, 2021). The badminton training incorporates aerobic conditioning and repetitive high intensity exercises. Athletes may have significant autonomic adaptations, which enable them to recover well from one training session to the next.

The practical ramifications of this work are significant for strength and conditioning specialists, coaches and sports scientists. Monitoring HRR after standardized bouts of exercise is an easy, affordable and noninvasive way to determine cardiovascular fitness and recovery state. Regular HRR evaluation allows coaches to avoid overtraining, identify poor recovery, alter training loads, and monitor seasonal adjustments. In addition, HRR measures are simple to implement in the field, need little equipment and may be added into normal athlete monitoring programmes.

Despite these noteworthy discoveries, a number of cautions should be mentioned. The study was confined to twelve male university badminton players at the beginning, which limits the generalizability of results. Secondly, only descriptive statistical analysis could be performed, as more elaborate analyses would not be possible without individual participant data. Third, comparisons between sexes and training status were not possible because female athletes and non-athletic control participants were not recruited. Finally, a more thorough assessment of cardiovascular recovery might have been provided by measuring additional physiological variables such as maximum oxygen uptake (VO2max), heart rate variability (HRV), blood lactate concentration and subjective effort.

Future studies should include a larger and more diverse sample, including female badminton players and athletes from different levels of competition, and also adequate control groups. Longitudinal investigations of HRR changes during training and competition seasons may be important for better understanding of cardiovascular adaptations in badminton athletes. More thorough data on athlete performance and exercise recovery can also be provided by more advanced measurements such as blood lactate, heart rate variability, VO 2 max, and wearable sensor technology.

In summary, the results of this study indicate that male college level badminton players exhibit a quick recovery of heart rate in early post-exercise period followed by delayed drop to resting levels. These recovery kinetics support the use of HRR as a valuable biomarker of cardiovascular fitness and exercise recovery in badminton players and also show good autonomic modulation.

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