# Match Analysis and Temporal Patterns of Fatigue in Rugby Sevens

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**Title.** Match Analysis and Temporal Patterns of Fatigue in Rugby Sevens

**Running title.** Motion analysis in Rugby players

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## ABSTRACT

Rugby sevens is a rapidly growing sport. Match analysis is increasingly being used by sport scientists and coaches to improve the understanding of the physical demands of this sport. This study investigated the physical and physiological demands of elite men's rugby sevens, with special reference to the temporal patterns of fatigue during match-play. Nine players, four backs and five forwards (age 25.1±3.1 yrs) participated during two "Roma 7$^{s}$" international tournaments (2010 and 2011). All players were professional level in the highest Italian rugby union, and five of these players also competed at the international level. During the matches (*n*=15) players were filmed in order to assess game performance. Global positioning system (GPS), heart rate (HR), and blood lactate (BLa) concentration data were measured and analyzed. The mean total distance covered throughout matches was 1221±118m (first half = 643±70m and second half = 578±77m; with a decrease of 11.2%, $p>0.05$, Effect Size = 0.29). Players achieved 88.3±4.2% and 87.7±3.4% of HR max during the first and second half, respectively. The BLa for the first and second half was 3.9±0.9 mmol·L$^{-1}$ and 11.2±1.4 mmol·L$^{-1}$, respectively. The decreases in performance occurred consistently in the final 3 minutes of the matches (-40.5% in distance covered per minute). The difference found in relation to the playing position, although not statistically significant ($p=0.11$), showed a large ES ($\eta^2=0.20$), suggesting possible practical implications. These results demonstrate that rugby sevens is a demanding sport that places stress on both the anaerobic glycolytic and aerobic oxidative energy systems. Strength and conditioning programs designed to train these energy pathways may prevent fatigue-induced reductions in physical performance.


**Key words:** rugby sevens; time–motion analysis; match–play demands; team sports.

## INTRODUCTION

Rugby sevens is played by two teams of seven players, on a regular rugby pitch. The game is derived from the original game of rugby union, applying essentially the same laws. The duration of the match is fourteen minutes (two seven minutes halves) with a two minute half-time interval. In recent years, a large number of time motion analyses have been conducted in soccer (3,8,24,26,33), rugby union (7,9,10) and rugby league (6,19). Few researchers have investigated the physical demands and activity profiles of rugby sevens (11,12,20,27,32), with the majority of these studies oriented to medical and traumatological aspects of the sport. Takahashi et al. (32) showed that the cumulative effects of two rugby sevens matches in one day negatively affected the athlete's immune system. Moreover, Fuller et al. (11) demonstrated that the risk and severity of injuries in rugby sevens was higher than that during international rugby union matches. Gabbett (12) also examined the incidence of injury in rugby sevens and showed that injury rates were higher than conventional rugby, with player fatigue contributing to injuries.

Recently, some authors (29-31) have described the physiological and kinematic aspects of rugby sevens. Using global positioning system (GPS) technology, these studies (30-31) have provided general indications on the physical and physiological demands of an entire rugby sevens match (4,17). Higham et al. (16) studied the physiological, anthropometric and performance characteristics of rugby sevens players. In contrast to 15-a-side players, their results showed small between-athlete variability in characteristics, highlighting the need for relatively uniform physical and performance standards in rugby sevens players (16). Knowledge of the activity profiles and movement demands of rugby sevens allows sport scientists and strength and conditioning staff to plan game-specific training sessions and programs in order to improve the physical condition of players. This information may also be used to evaluate the physical performance of individual players (1).

Researchers (18,25) have studied the temporal patterns of physical match performance in different team sports. Other studies have investigated the decline in physical performance from the first to the second half in order to gain insight into the fatigue that may occur across the course of a match (26). Understanding how physiological and technical-tactical parameters change during a match or in tournaments may provide important insight into causes of fatigue and how this fatigue may affect the individual player. These patterns, when consistent, can also be interpreted as useful indicators of the trends of the variables under study. Mohr et al. (23) has described the fatigue that may develop during soccer matches and has provided potential physiological mechanisms responsible for fatigue in soccer. The reduced match performance that occurs as a consequence of fatigue seems to occur at three different stages: after short-term intense periods in both halves; in the initial phase of the second half; and towards the end of the game (23).

While the physical demands of soccer have been extensively investigated, no similar studies have been performed in rugby sevens. To date, only Higham et al. (15) have quantified the differences in movement patterns between domestic and international rugby seven tournaments, the effects of fatigue within and between matches during tournaments, and the movement patterns of second half substitute players. The results of the study highlight some significant differences between domestic and International Rugby seven tournaments, with greater distance covered at high speed and greater accelerations and decelerations performed in international matches. A decrease in speed and the number of changes in speed was found between the first and second half. Moderate reductions were also observed between the first match (played on day one) and the last match (played on day two) of the tournament. Although the study by Higham et al. (15) improved our understanding of rugby sevens, no information was provided on the temporal patterns of fatigue. In addition to fatigue-induced performance reductions from the first to second half, it is likely that fatigue may also occur transiently throughout the course of a match. Therefore, the purpose of the present study was to address this gap in the literature by investigating the physical and physiological demands of rugby sevens, with special reference to temporal patterns of fatigue, analyzed minute by minute during international match-play. It was hypothesized that transient fatigue, as evidenced by reductions in movement intensities, would occur towards the end of each half in rugby sevens.

## METHODS

### Experimental approach to the problem

In order to study the physical demands of rugby sevens match-play, we performed kinematic (GPS and Motion Analysis) and physiological (heart rate and blood lactate concentration) measurements during fifteen matches of the 2010 (*n*=7) and 2011 (*n*=8) International "Roma Sevens" competition. Total distance covered, percentage of time spent in two distinct (low and high) speed zones, and heart rate (HR) were recorded each minute of match-play in order to gain an understanding of the temporal patterns of fatigue.

### Subjects

Nine rugby sevens players, 4 backs and 5 forwards, (age 25.1±3.1 yrs; body mass 86.0±9.4 kg; height 180.5±3.5 cm; body mass index 27.7±2.6 $kg \cdot m^{-2}$; $VO_{2max}$ 52.1±3.4 $ml \cdot kg^{-1} min^{-1}$) participated in the study. All players competed at professional level in the highest Italian rugby union ("*Campionato Italiano di Eccellenza*"), with five of these players also competing at international level. Players had a minimum rugby training experience of 5 years. The typical weekly training volume was 14-16 hours, which included four-five technical training sessions (10-12 hours) and three sessions of physical preparation (4-6 hours). Each player was informed about the study, including the risks and benefits and provided written informed consent, in conformity with the Ethical Code of the World Medical Association (Declaration of Helsinki). The Tournament Directors also provided clearance for the use of GPS in matches before the commencement of the study. All experimental procedures were approved by the institutional human ethics committee.

### Experimental Procedures

The match activity and physiological data were collected over two competitive tournaments. All matches were played on a dry, full-sized rugby pitch (100 × 70 m), covered by natural grass.

Matches were played between 11.00 a.m. and 4.00 p.m. GPS, heart rate, and motion analysis were synchronized, set with the solar time, so as to know the range for the first half, rest time, and second half. The average temperature and relative humidity for the matches ranged from 24-26ºC and 67-72%, respectively. During the week before the tournaments, each player underwent measurements of standard anthropometry (body mass and height) and the Yo-Yo Intermittent Recovery Test Level 2 was performed in order to measure the individual maximum heart rate (HRmax) (21). Heart rate was recorded continuously throughout the Yo-Yo test using Polar Team System heart rate monitors (Polar Electro OY, Kempele, Finland) sampling at 0.20 Hz.

**GPS Data**

A portable GPS device (SPI Elite, GPS Sports Systems Ltd., Canberra, Australia), sampling at 1 Hz, was used. Players were asked to wear an individual GPS unit (mass: 80 g; dimensions: 91×45×21 mm) encased within a protective harness between the player's shoulder blades in the upper thoracic-spine region. Five minutes before each match the GPS device was fixed to the torso of the athlete in accordance with the manufacturer instructions. The device was activated and satellite lock established for a minimum of 15 min before the commencement of each match. GPS data were analyzed using Microsoft Excel and statistical software.

The GPS files were 'cleaned' with Spi Elite software (Team AMS; GPSports, V.1.2) so that only time spent on the field was included in the analysis. Data were log-transformed prior to analysis to reduce the non-uniformity of error and back-transformed to obtain differences in means and variation as percentages. In accordance with Hartwig et al. (14), the data were divided into two speed zones, corresponding to low ($0.1<14.0$ km·h$^{-1}$) and high intensities ($>14.1$ km·h$^{-1}$). The chosen velocity zones represented the range of locomotor activity profiles typical of intermittent team sport and are routinely (14) used during GPS monitoring in rugby-specific match-play (13).

**Heart Rate**

Players wore a heart rate belt (Polar Team System, Polar Electgro OY, Kempele, Finland) recording the heart frequency (HR) during the 15 matches. Heart rate data was synchronized with GPS data so to exclude rest periods. One minute averages were calculated for heart rate data. Taking into consideration that rugby involves strong physical contacts among players during match-play, the thorax belt was reinforced and fixed with elastic tape and other bandages around the thorax and shoulders. The recorded data were downloaded and analyzed using Polar Precision Performance™ v.4.03.043 software. Data involving game interruptions, and time spent off the field were excluded from subsequent analysis. The HR was expressed as a percentage of the maximum heart rate (HRmax) measured in the Yo-Yo Intermittent Recovery Test Level 2 (2).

**Blood Lactate Concentration**

Capillary blood samples were drawn from the ear lobe of four players (*n*=4), using a sterile lancet (Accu-Check Softclix, Roche - 5µ) immediately after the warm up, at the end of the first half, and at the end of the match. Blood samples were analysed for blood lactate (BLa) concentration. Three blood lactate analyzers (LactatePro™, Arkray, Japan) were used for the analysis of the samples. All blood analysis was made within two minutes from the end of each considered period. The validity of the utilized instrument (Lactate Pro Analyser) has been verified previously (22).

**Video recording**

All the matches were filmed using a single camera (Sony Handycam DCR-SX 30), placed 12 meters above the field and at the end of one diagonal, in order to always have the view of the full field. The exact video recorded times (start and end of each part of the game), playing position (back or forward), and replacements; interruptions of the game were used in post-analysis of kinematic GPS and physiological data (HR and BLa) (28).

**Statistical Analysis**

Data are presented as mean (*M*) ± standard deviation (*SD*) The assumption of normality was assessed using the Shapiro-Wilk test. Parametric and nonparametric statistics were used when appropriate. To identify the differences in distance covered between first and second half, a paired *t*-test was used. To identify differences in physical and physiological variables over time (first and second half) between forwards and backs a two-way group x time repeated measures ANOVA was also performed. After performing the Mauclhy test of sphericity, the Greenhouse-Geisser ε was used when appropriate. Effect sizes (ES) in ANOVA were computed as partial $\eta^2$, to assess meaningfulness of practical differences, with $\eta^2$ <0.01, 0.01< $\eta^2$ <0.06, 0.06< $\eta^2$ <0.14 and $\eta^2$ > 0.14 considered trivial, small, moderate, and large, respectively.

In addition to the null hypothesis testing, effect sizes (Cohen's *d*) were reported for all normally distributed data (5). Absolute effect sizes of 0.20, 0.50, and 0.80 represented small, moderate, and large differences, respectively. The corresponding "P" values were provided for each analysis. Statistical significance was accepted at $p \leq 0.05$. Statistical package for Social Sciences (SPSS 15.0) for Windows was used to analyze and process the collected data.

**RESULTS**

The mean total distance covered throughout the matches, and in the first and second halves was 1221±118, 643±70 and 578±77 m, respectively. Although a reduction in total distance covered between halves was found (-11.2%), it was not statistically significant [paired *t*-test: t= 1.823; df=7; *p*=0.111; ES as Cohen *d*= 0.29]. A difference in positional play (backs, n=4 and forwards, n=5) was observed between halves for total distance covered (Factorial ANOVA; *p*=0.03). In the first half, the backs covered 677±60 m whereas the forwards covered 599±60 m. In the second half, the backs covered 615±87 m whereas the forwards covered 540±51 m.

Table 1 shows the proportion of distances covered and time spent in the two different intensity zones. There were no significant differences between halves for the distances covered in these two different speed zones. Small to moderate ES (0.41< Cohen *d*< 0.56). were found for these differences. A meaningful reduction (ES as Cohen *d*= 1.37) in distance covered per minute for each half of the matches was observed (91.4±13.6 *vs.* 78.5±18.3 $m \cdot min^{-1}$, Paired *t*-test: t=1.438; df= 6; *p*=0.200).

**Total Distance Covered per Minute**

The distance covered per minute of match-play throughout the match is provided in Figure 1. Repeated measure ANOVA showed statistically significant differences among each minute of the game [repeated measure ANOVA with adjustment Greenhouse-Geisser ε, $F_{(3.06;\ 60.21)}$= 3.065; *p*=0.016; ES as partial $\eta^2$= 0.203; Power= 0.839; α= 0.05] providing a standard profile of the game (Figure 1).

**Percentage of Time Spent in Each Speed Zone per Minute**

No significant differences were found among each minute of the game for the percentage of time spent in each speed zone. The relevant statistics are reported in Table 1.

*Insert Table 1 About Here*

**Differences in Positional Play**

No statistically significant differences were found between playing positions total distance covered per minute: (Two-way group × time repeated measures ANOVA: $F_{(1,12)}$=2.97; *p*=0.11; ES as partial $\eta^2$=0.198; power 0.354 with α=0.05). Nonetheless the large ES found suggests some practical implications, worth consideration by the coaches and conditioning staff. Figure 2 highlights the different work rates of each positional role (back and forward) for each minute of the game.

*Insert Figure 1 About Here*

**Heart Rate**

The mean and the peak values of HR, expressed as a percentage of the estimated maximal heart rate, recorded during the matches, are provided in Table 2 and Figure 3. The players spent approximately 86% of the total match time at or above 90% of their individual maximal HR (Figure 3).

*Insert Figure 2, 3 and Table 2 About Here*

**Heart Rate During Each Minute of Match-Play**

Repeated measures ANOVA confirmed statistically significant differences for mean ($F_{(13,104)}$= 2.057; $p$=0.023; partial $\eta^2$=0.205; power 0.924 with α= 0.05) and peak ($F_{(13,117)}$= 4.024; $p$<0.001; partial $\eta^2$=0.309; power 0.999 with α= 0.05) heart rates recorded during the matches, with particular reference to the very first minute of the first and second half, respectively.

**Blood Lactate Concentration**

Blood lactate concentration sampled at the end of warm-up, at the end of half time, and at the end of the match were 3.9±0.9, 8.7±1.7 and 11.2±1.4 $mmol \cdot L^{-1}$ respectively. A significant difference ($p$=0.017, Cohen $d$= -1.5) was found between the values recorded at the end of the first and second half, respectively. No significant differences were found in post-match BLa (Mann-Whitney U-Test; $p$=0.19, Cohen $d$= 0.29) between backs (11.6±1.5 $mmol \cdot L^{-1}$) and forwards (10.4±0.8 $mmol \cdot L^{-1}$).

**DISCUSSION**

To our knowledge, this is the first study to investigate the temporal patterns of physical performance and physiological parameters measured during international level rugby sevens tournament match-play. Our data highlight the physical loads observed in rugby sevens, and consider the contrasting movement demands of different playing positions (backs and forwards). Significant fatigue, identified as the rate of decay in performance, was observed during match-play. A reduction of 11.2% between the first and second half was observed for total distance covered per minute. While not statistically significant (*p*=0.16), the reduction in performance would certainly be considered practically meaningful, with a large effect size when considered as distance covered per minute of match-play. The difference found in relation to the playing position (Figure 2), although not statistically significant (*p*=0.11), showed a large effect size, indicating possible practical implications.

We also conducted a minute by minute analysis on the total distance covered by players during the matches. In relation to this parameter, it should be noted that the pace of the game has a significantly different modulation when seen minute by minute, allowing us to identify some "temporal patterns" on the second, seventh, and eleventh minute of the match. Such typical modulations of the matches were found to be significant and consistent in all of the investigated games. These reductions in performance may suggest that rugby sevens players experience transient fatigue during match-play.

By reporting the percentages of time spent in each speed zone per minute (Table 1), we found significant differences both in relation to match time, and positional play, as an interaction effect between the minute of play and the positional play. These findings provide evidence of both fatigue occurring transiently throughout rugby 7$^{s}$ matches, and the position-specific nature of this fatigue. The observed differences in low and high-speed activity provide some interesting observations about international rugby sevens. On a minute-by-minute basis, the two speed zones fluctuated considerably (ES as $\eta^2$ >0.12**)** (Table 1, Figure 1). These findings may reflect differences in playing tactics or positional play. Alternatively, it is possible that the fluctuations in low-speed activity represent a pacing strategy used on behalf of players to preserve high-speed activity. The trend in mean (88.0±3.7% of $HR_{max}$) and peak (92.4±4.0% of $HR_{max}$) heart rate observed during all the investigated matches demonstrates the very intense physiological demands required to compete in international level rugby sevens. It also shows that the mean and peak HR values reached the operating level (~90% of the $HR_{max}$) after the first two minutes of play, both in the first and in the second half.

Our blood lactate concentration data confirm the glycolytic nature of rugby seven's matches. In particular, we emphasize that the blood lactate concentrations found in rugby seven's matches are greater than the average blood lactate concentration found during conventional rugby union match-play for backs (5.1 $mmol \cdot L^{-1}$) and forwards (6.6 $mmol \cdot L^{-1}$), confirming that rugby sevens presents different and greater physiological demands than those required in conventional rugby union (9). However, it should be noted that if match involvements increased towards the end of the first and second half, then this could significantly increase blood lactate concentrations above normal match values.

## PRACTICAL APPLICATIONS

There are several practical applications from this study that have relevance to the strength and conditioning coach. Firstly, these findings demonstrate the highly intense, glycolytic nature of international rugby sevens match-play. Mean heart rate (88.0% $HR_{max}$) during and blood lactate concentration (11.2 $mmol \cdot L^{-1}$) following match-play demonstrate that strength and conditioning coaches should emphasize the development of anaerobic glycolytic energy pathways and aerobic capacities for this sport. Our minute by minute analysis also revealed significant reductions in physical performance, indicative of fatigue, or possibly pacing, throughout various stages of matches. These findings could be used by both applied sport scientists and rugby coaches to inform strategic interchanges throughout match-play. For example, with the introduction of 'live streaming' of GPS data, movement patterns can be observed in real-time, and interchanges made prior to the onset of fatigue, and reductions in performance. Finally, our results show similarities in the physical demands of rugby sevens backs and forwards. These findings may be a reflection of the greater space afforded to players in Sevens, and the consequent reduction in the number and intensity of collisions compared to the conventional 15-a-side game. These findings suggest that similar strength and conditioning programs can be used for forwards and backs to prepare these players for the physical demands of international rugby sevens match-play.

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**Figure caption**

**Figure 1.** Percentage of distance covered at each intensity zone per minute of match-play during international rugby sevens.

**Figure 2.** Total distances covered by backs and forwards per minute during international rugby sevens match-play. *N*= 4 backs and 5 forwards.

**Figure 3.** Heart rate per minute of match-play during international rugby sevens.

**Table 1**. Percentage (%) of time spent and distance covered in each intensity zone per half in international rugby sevens match-play.

| Variable | Speed zone | 1st half (%) | 2nd half (%) | (Δ%) | Paired *t*-test | Cohen's D |
|---|---|---|---|---|---|---|
| Distance (%) | 0.1<14 $km \cdot h^{-1}$ | 92.85(1.69) | 93.20(1.79) | 0.13 | *t*= -0.24; df=12; *p*=0.81 | ES= -0.08 |
| | > 14.1 $km \cdot h^{-1}$ | 7.13(1.68) | 6.82(2.48) | -1.76 | *t*= 0.12; df=12; *p*=0.91 | ES= 0.04 |
| Times (%) | 0.1<14 $km \cdot h^{-1}$ | 75.63(5.62) | 78.29(5.63) | 3.4 | *t*= -1.36; df=12; *p*=0.19 | ES= 0.56 |
| | > 14.1 $km \cdot h^{-1}$ | 24.42(5.65) | 21.71(5.55) | -12.49 | *t*= 1.49; df=12; *p*=0.16 | ES= 0.41 |

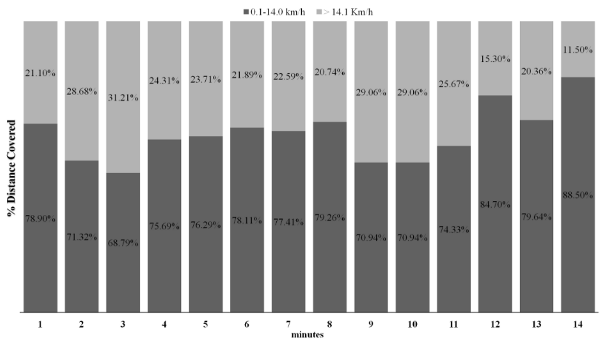
| Speed zone | Repeated measure ANOVA |
|---|---|
| 0.1<14.0 $km \cdot h^{-1}$ | **MF**: $F^*_{(4.78, 57.30)}$= 1.70; *p*=0.15; partial $\eta^2$=0.12; power 0.814 with $\alpha$ = 0.05<br>**I**: $F^*_{(4.78, 57.30)}$= 0.88; *p*=0.49; partial $\eta^2$=0.07; power 0.294 with $\alpha$=0.05 |
| > 14.1 $km \cdot h^{-1}$ | **MF**: $F^*_{(5.10, 66.40)}$= 1.88; p=0.11; partial $\eta^2$=0.13; power 0.611 with $\alpha$=0.05<br>**I**: $F^*_{(5.10, 66.40)}$= 0.95; p=0.46; partial $\eta^2$=0.07; power 0.564 with $\alpha$=0.05 |
| | **Two-way group × time repeated measures ANOVA** |

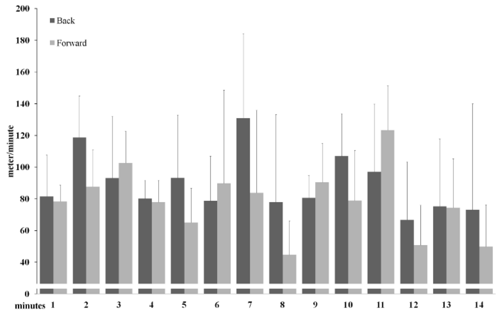
All value are presented as mean and standard deviation (Distances covered and time spent). Speed zone represents the velocity (0.1<14 *vs*. >14 $km \cdot h^{-1}$) expressed as a percentage (%) during the 1st and 2nd half of match-play, the difference between the 1st and 2nd half as a ratio (Δ%), and effect size (Cohen's D). The time spent in each speed zones (class of velocity 0.1< 14.1 $km \cdot h^{-1}$) in percentage (%). *Main Factor (MF): minute of the match; Interaction (I): minute × role.

**Table 2**. Mean and peak percentage $HR_{max}$ during international rugby sevens match-play.

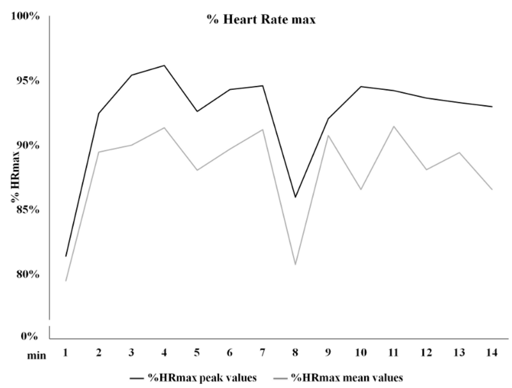
| | **First Half** | **Second Half** | **Whole match** |
|---|---|---|---|
| **Mean** $\%HR_{max}$ | 88.3±4.2% | 87.7±3.4% | 88.0±3.7% |
| **Peak** $\%HR_{max}$ | 92.3±5.5% | 92.4±2.9% | 92.4±4.0% |

All value are presented as mean and SD, data are mean and peak values recorded per half.
Mean $\%HR_{max.}$ First Half *vs.* Second Half: paired *t*-test (t=0.658; df=6; *p*=0.535).
Mean $\%HR_{max.}$ First Half *vs.* Second Half: paired *t*-test (t= -0.157; df=6; *p*=0.881).


0.1-14.0 km/h
> 14.1 Km/h
% Distance Covered
21.10%
28.68%
31.21%
24.31%
23.71%
21.89%
22.59%
20.74%
29.06%
29.06%
25.67%
15.30%
20.36%
11.50%
78.90%
71.32%
68.79%
75.69%
76.29%
78.11%
77.41%
79.26%
70.94%
70.94%
74.33%
84.70%
79.64%
88.50%
1
2
3
4
5
6
7
8
9
10
11
12
13
14
minutes



200
180
160
140
120
100
80
60
40
0
meter/minute
Back
Forward
minutes
1
2
3
4
5
6
7
8
9
10
11
12
13
14


% Heart Rate max
100%
95%
90%
85%
80%
0%
% HRmax
min
1
2
3
4
5
6
7
8
9
10
11
12
13
14
%HRmax peak values
%HRmax mean values