The Impact of Rest Duration on Work Intensity and RPE during Interval Training

**Article** in Medicine & Science in Sports & Exercise · September 2005
DOI: 10.1249/01.mss.0000177560.18014.d8 · Source: PubMed

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The Impact of Rest Duration on Work Intensity and RPE during Interval Training

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ABSTRACT

SEILER, S., and K. J. HETLELID. The Impact of Rest Duration on Work Intensity and RPE during Interval Training. Med. Sci. Sports Exerc., Vol. 37, No. 9, pp. 1601–1607, 2005. Purpose: To investigate the effect of rest duration on self-selected intensity, physiological responses, and RPE during interval training prescription. Subjects: Nine well-trained male runners (VO_{2max} 71 ± 4 mL·kg^{-1}·min^{-1}) performed three treadmill interval training sessions running at constant 5% incline. Six 4-min work bouts with either 1-, 2-, or 4-min recovery periods were performed in each session. Sessions were prescribed as “high-intensity” workouts with the goal being to achieve the highest possible average running speed for the work intervals. Subjects regulated their work and rest intensity based on these instructions. In a fourth interval session, subjects self-selected recovery time in response to a fixed intensity. Results: Running velocity increased slightly (14.7 ± 0.7 vs 14.4 ± 0.8 km·h^{-1}, P = 0.02) when rest increased from 1 to 2 min, but showed no further increase with a 4-min rest (14.7 ± 0.6 km·h^{-1}). Work VO_{2} was slightly higher with a 2-min rest duration compared with 1 and 4 min (66.2 ± 4.2 vs 65.1 ± 4.2 and 64.9 ± 4.7 mL·kg^{-1}·min^{-1}, P < 0.05). Peak blood lactate was similar (6.2 ± 2.6, 6.8 ± 2.9, 6.2 ± 2.6 mmol·L^{-1}) across conditions, whereas peak RPE was slightly lower during the 4-min rest condition (17.1 ± 1.3, 17.7 ± 1.5, 16.8 ± 1.5, P < 0.05). With self-selected recovery time and no knowledge of elapsed time, the average rest duration was 118 ± 23 s. Conclusions: Under self-paced conditions, varying rest duration in a range of 1 to 4 min had limited impact on performance during repeated 4-min high-intensity exercise bouts. Approximately 120 s of active recovery may provide an appropriate balance between intracellular restitution and maintenance of high VO_{2} on-kinetics. Key Words: INTERMITTENT EXERCISE, PACING, ENDURANCE, RUNNING, TELEOANTICIPATION

Training lore suggests that interval training has been used in one form or another by endurance athletes for nearly 100 yr. Regular interval training has become viewed as an indispensable component in the endurance athlete’s training repertoire. The goal of interval training, then and now, is to accumulate a greater training stimulus at high exercise intensities compared to what can be tolerated then and now, is to accumulate a greater training stimulus at high exercise intensities compared to what can be tolerated. The interval training prescription consists of five variables: work interval intensity and duration, recovery interval intensity and duration, and total work duration (work interval number * work duration). These variables can be manipulated to generate a large range of interval training prescriptions designed to primarily stress either aerobic or anaerobic energy metabolism. Sufficient physiological data are now available to classify different types of aerobic interval sessions ranging in intensity between 85 and 130% of the power or velocity associated with VO_{2max} (2,3).

Most published data quantifying acute physiological responses to high-intensity aerobic intermittent exercise are based on measurement of responses to fixed work intensities at a predefined percentage of maximal aerobic power or velocity (5,6,10,27). Although the fixed-intensity approach to studying interval training responses has been very informative, it is often difficult to achieve in training practice. Work intensity is not a stable function of velocity in many sports due to variable terrain, wind, water conditions, snow conditions, etc. Consequently, interval training sessions are typically prescribed using manipulation of the independent variables interval duration (distance or time), rest duration, and number of work bouts (i.e., 8 × 3-min work with 2-min walk recoveries). The athlete determines the dependent variable, exercise intensity. Performance during this exercise situation seems likely regulated by interpreting the biochemical and biomechanical signals associated with a given work intensity and extrapolating them to arrive at a goal pace sustainable over the planned work duration. This coupling process between physiological feedback signals, perception, and pacing of effort over a given duration has been termed teleoanticipation (29). Whereas the teleoanticipation...
concept has been discussed (25) and experimentally explored (14,20,23) with reference to a steady-state exercise model, it is also relevant to intermittent exercise.

Our interest has been to recreate this common interval training scenario in the laboratory to better understand how athletes actually respond to different interval training prescriptions perceptually and physiologically. Two critical variables in the interval training prescription are the duration of the work interval and the duration of the rest interval. In a previous study, we examined how variation in work interval duration in a range of 1–6 min affected physiological responses and perceived exertion during interval training sessions where well-trained endurance athletes were uniformly instructed to perform a “high-intensity interval session” (24). In the present study, we examined how rest interval duration during intense aerobic interval training affects achieved exercise performance, physiological responses, and perceived exertion.

METHODS

Subjects

Twelve well-trained male distance runners and orienteers volunteered to participate in this investigation, which was approved by the human subjects research review board of the Department of Health and Sport, Agder University College. Before providing written consent, participants were informed of the risks associated with the study and assured that they could terminate participation at any time. The athletes were all familiar with high-intensity aerobic interval training as well as training and testing on a motorized treadmill. During the data collection period, one athlete became injured and had to withdraw from the investigation. The remaining 11 athletes completed the study. However, two of these did not comply with the intensity prescription for the interval sessions, choosing instead to restrain their running velocity to ensure a lower lactate response in keeping with their training philosophy and the time of the season. This observation was confirmed in discussions with the two athletes. For this reason, the results presented here are based on the nine athletes who fully complied with the training instructions.

Preliminary Testing

One week before starting the interval training sessions, athletes performed a continuous ramp protocol run to exhaustion for the purpose of quantifying maximal oxygen consumption (\(\dot{V}O_2\text{max}\)), running velocity at maximal oxygen consumption (\(\gamma\dot{V}O_2\text{max}\)), maximal HR (\(HR_{\text{max}}\)), peak blood lactate concentration, and RPE\(_{\text{peak}}\). Both preliminary testing and subsequent interval training bouts were performed on a motorized treadmill (Woodway ELG55, Weil am Rhein, Germany) at constant 5% incline. After a 20-min warm-up, the test was initiated with a 3-min run at 7 \(km\cdot h^{-1}\) with subsequent increase of 0.75 \(km\cdot h^{-1}\) every minute until voluntary exhaustion. One minute after exhaustion, blood was collected from a finger to quantify peak lactate concentration (Lactate Pro LT-1710, Arkay KDK, Japan).

Fixed Recovery Time Trials

For three consecutive weeks, each athlete replaced one scheduled hard training session with an interval session performed in the laboratory. Each session consisted of six work periods of 4-min duration (i.e., total work of 24 min). The only difference among the three interval sessions was the rest interval duration, which was randomly changed each week and equaled either 1, 2, or 4 min. Subjects performed the three interval sessions at the same time of day each week. Standardized written instructions were given before each test. Subjects were asked to treat each interval session as a “high-intensity” interval session. They were also instructed to attempt to maintain the highest average running velocity they could across all the work bouts of each interval session. Athletes performed the work bouts without feedback about their actual running velocity, oxygen consumption, or blood lactate concentration. However, the athletes were regularly updated about the time remaining in each work and rest period.

The end of the warm-up was used to determine the starting velocity for the first work period. Thereafter, velocity could be increased or decreased at any time via a hand signal. At frequent intervals, subjects were queried as to whether they desired “more or less speed.” During recovery periods, treadmill velocity was initially set to 5 \(km\cdot h^{-1}\), which the subjects could change as desired. Each new work bout was started at the velocity at which the subject completed the previous work bout unless otherwise instructed. A small, motorized fan, positioned in the front of the athlete at chest height, was used to ensure effective evaporative cooling. Laboratory temperature during all training sessions was 18–20°C.

Self-Selected Recovery Duration Trial

In a fourth laboratory training session, completed after the 3-wk block of variable rest duration sessions, subjects performed the same six bouts of 4 min with the same instructions regarding the goal intensity of the training session. However, in this trial, running velocity was held constant at the highest average velocity achieved during the three previous training sessions. The subjects determined recovery duration subjectively between each work period without feedback regarding elapsed time or HR during recovery. They were instructed to select the minimum recovery time necessary to maintain the fixed intensity and complete the training session. The recovery time used between each work bout was recorded to the nearest second.

Measurements during Interval Training

Running velocity, gas exchange, and HR data were collected continuously. Blood lactate samples were collected within 20 s after the first, third, and sixth work periods. During the interval session with 4-min recovery periods,
additional lactate measurements were collected at the end of the first and third recovery periods. Perceived exertion was measured at the end of each work period using the 15-point Borg RPE scale. Before each training session, subjects were provided with standard written instructions explaining the interpretation of the Borg scale.Expired gas samples were measured continuously using an Oxycon Pro breath-by-breath system (Oxycon, Jaeger BeNeLux Bv, Breda, The Netherlands), the validity and reliability of which have been verified (8). Calibration was performed before each test according to manufacturer instructions. \( \dot{V}O_{2\text{max}} \) was defined as the highest 30-s average measurement recorded during the ramp test. The running velocity at maximal oxygen consumption \( (v\dot{V}O_{2\text{max}}) \) was defined as the lowest treadmill velocity corresponding to the 30-s period defining \( \dot{V}O_{2\text{max}} \). HR responses were collected every 5 s using a telemetry system (Polar, S610, Kempele, Finland).

### Training Control

This study was carried out during the precompetition preparation phase of training (January/February). Subjects were instructed to abstain from hard training the day before laboratory sessions. No special attempt was made to control the diet of the athletes. They were merely reminded to come to the training session well hydrated and nonfasted.

### Statistical Analyses

Physiological and RPE responses during the three different interval sessions were compared using the General Linear Model with repeated measures (SPSS 11.0). Recovery duration during the self-selected recovery trial was compared over the course of the training session using the same method. An alpha level of ≤0.05 was considered statistically significant.

### Results

#### Subject Characteristics

The physical characteristics of the subjects are presented in Table 1. At the time of the study, all athletes were training 6 to 10 sessions per week, of which one to two were of high intensity.

<table>
<thead>
<tr>
<th>Subject Characteristics</th>
<th>Mean (SD)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>30 (4)</td>
<td>24–35</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>181 (6)</td>
<td>170–190</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>72 (5)</td>
<td>66–81</td>
</tr>
<tr>
<td>HRmax (bpm)</td>
<td>193 (9)</td>
<td>178–208</td>
</tr>
<tr>
<td>(Lactate ( \text{[mmol} \cdot \text{kg}^{-1} ))</td>
<td>12.6 (2)</td>
<td>8.9–14.3</td>
</tr>
<tr>
<td>RPE(_{\text{peak}})</td>
<td>18.3 (0.7)</td>
<td>17–19</td>
</tr>
<tr>
<td>( \dot{V}O_{2\text{max}} ) (mL·kg(^{-1})·min(^{-1}))</td>
<td>72 (5)</td>
<td>65–79</td>
</tr>
<tr>
<td>( v\dot{V}O_{2\text{max}} ) (km·h(^{-1}))</td>
<td>17.6 (1)</td>
<td>15.8–19.5</td>
</tr>
</tbody>
</table>

All treadmill testing was performed at a constant incline of 5%.

### Effect of Varying Rest Duration on Interval Training Characteristics

#### Running velocity.
Increasing the recovery period from 1 to 2 min resulted in an increase self-selected in running velocity from 83 to 85% of \( v\dot{V}O_{2\text{max}} \) \( (P = 0.024) \). However, a further increase to 4 min had no additional effect on running velocity (84% \( v\dot{V}O_{2\text{max}} \)). The 95% CI for the absolute increase in running velocity associated with increasing the rest interval from 1 to 2 min was 0.08 to 0.59 km·h\(^{-1}\). All athletes chose to walk during the recovery period (mean velocity 4.8–5.0 km·h\(^{-1}\)), and the average velocity during the recovery periods was not significantly influenced by the recovery duration.

#### Oxygen consumption.
Oxygen consumption (averaged over the last 3 min of each 4-min bout) followed a similar trend as running velocity (65.1 ± 3.3 vs 66.2 ± 3.1 and 64.9 ± 3.6 mL·kg\(^{-1}\)·min\(^{-1}\), for 1-, 2-, and 4-min rest conditions, respectively, \( P < 0.05 \)). The 95% CI for the true effect of increasing the rest duration from 1 to 2 min on average oxygen consumption during work bouts was 0.24–2.4 mL·min\(^{-1}\)·kg\(^{-1}\). Peak oxygen consumption achieved during the interval sessions averaged 94–95% of the \( \dot{V}O_{2\text{max}} \) established during preliminary testing for the three rest duration conditions (range 89–101%).

#### Blood lactate.
Blood lactate concentration reached 4 mmol·L\(^{-1}\) immediately after the first work bout and continued to climb slowly to an average of 6–7 mmol·L\(^{-1}\) by the end of the sixth work bout (Fig. 1). Increasing the rest duration from 1 to 4 min did not significantly affect blood lactate responses during the interval sessions. During the 4-min recovery duration trial, blood lactate concentration was measured both at the beginning and at the end of the first and third recovery periods. These measurements showed that blood lactate concentration decreased by 1.5 ± 0.5 mmol·L\(^{-1}\) during 4 min of walking recovery.

#### HR.
Averaged heart responses during the three interval sessions are presented in Figure 2. Peak HR, averaged across all six work bouts, was essentially identical for all three conditions (179 ± 8, 179 ± 7, and 178 ± 9 for 1-, 2-, and 4-min rest conditions, respectively, \( P < 0.05 \)).
and 4-min rest conditions, respectively). The peak HR recorded during each work bout drifted upward throughout all three training sessions by a similar amount (12 ± 4, 11 ± 4, and 13 ± 4 bpm). In contrast, the recovery HR, defined as the lowest HR recorded before the onset of each new work bout, drifted up significantly more in the 1-min recovery session compared to 2- or 4-min recovery (P < 0.05).

**RPE.** RPE increased linearly throughout the interval sessions (Fig. 3). The intensity was perceived as 14–15 or “hard” on the Borg scale after one work bout and reached 16–18 or “very hard” by the end of the interval session. RPE responses were quite similar across the three rest duration conditions. However, at the end of the sixth work bout, RPE was slightly but significantly higher with 2-min versus 4-min rest periods (17.7 ± 1 vs 16.9 ± 0.6, P < 0.05).

**Self-selected recovery duration at a fixed running velocity.** When running velocity was fixed during a fourth interval session to equal the average velocity that each athlete achieved during their “best” previous training session, the recovery duration selected by the athletes averaged 118 ± 23 s for the five recovery periods. Further, the self-selected rest duration remained essentially constant throughout the interval session (Fig. 4), despite increasing RPE and blood lactate concentration.

**DISCUSSION**

The key finding of this study is that within a range typically used for high-intensity aerobic interval training, a fourfold increase in recovery time had very little impact on running velocity or physiological responses during self-
paced interval training sessions performed by motivated, well-trained runners. Doubling recovery time from 1 to 2 min resulted in a 2% increase in average running velocity for the session. However, increasing the recovery time to 4 min did not induce an additional increase in achieved work intensity. In addition, when athletes selected their own rest duration (without feedback regarding elapsed time) during a fixed-intensity interval session, they chose about 120 s. Repeated high-intensity work bouts in the 3- to 6-min range appear to be performed at 90–100% \( \dot{V}O_{2\text{max}} \) by well-trained athletes (24) and have emerged as common prescription in their training (4,11,26,27). A practical conclusion from this study is that for this common training prescription, a fixed rest interval of 2 min is appropriate and preferable to using recovery HR as a guide.

In the present study design, each athlete’s response to the training prescription involved an integration of physiological capacity limitations at the cardiovascular and muscular level with a cognitive component regulating their voluntary intensity response within that capacity. The psychophysiology connecting chemical disturbances around the muscle cells and the brain’s interpretation of the resulting afferent feedback is central to such issues as performance pacing (12,16) and the related concept of teleoanticipation (14,25,29). These findings are also relevant to the prescription of intermittent exercise for fitness and performance enhancement.

Physiologically, a rapidly diminishing impact of intermittent recovery with increasing duration is consistent with our current understanding of cellular events in working muscle immediately following exercise cessation. Three key aspects of acute intracellular muscular recovery from intense exercise are repletion of phosphocreatine, removal of hydrogen ions, and restitution of the transmembrane potassium gradient. Although intracellular recovery was not assessed in the present study, a number of published studies provide insights that are relevant to our findings. Phosphocreatine recovery follows a two-phase time course, with a very rapid component during the first minute after work cessation (15,28). Potassium concentration shifts will also be largely rectified within 60 s (17,18), although intracellular potassium concentration will gradually decline during the interval session (30). In contrast, the \( t_{1/2} \) for the recovery of intracellular pH is much longer, generally reported to be in the range of 5–15 min (19,21,22). Whereas intracellular pH decline has long been hypothesized as an important cause of skeletal muscle fatigue, [H\(^+\)] changes have been temporally dissociated from muscular force decline and recovery (9). Changes in intracellular \([Pi]\) and \([H_2PO_4^-]\) appear to also play an important role in contractile fatigue (7,9). Intracellular recovery of these ions follows a more rapid time course such that 1–2 min of recovery would be sufficient to reestablish low intracellular concentrations for both ions and allow continued work at near \( \dot{V}O_{2\text{max}} \) intensity.

Subjects self-selected their running intensity based on a verbal and written prescription without feedback about their actual velocity. They achieved an average work intensity (90–100% \( \dot{V}O_{2\text{max}} \)) and blood lactate concentration (6–7 mmol\(L^{-1}\)), very similar to that observed in studies where the running speed has been fixed based on preliminary testing (5,13,23,27) and the recovery duration was within the same range. A common guideline for high-intensity aerobic interval training is that the work intensity selected in the initial work bouts should be maintained through the entire training session. It seems reasonable to expect that at even higher work intensities, the demand for recovery time would increase rapidly or the total number of repetitions would be necessarily reduced. However, results similar to ours were also reported by Balsom et al. (1) in repeated maximal 40-m sprints performed with varying recovery duration. Recovering for 120 s between sprints was sufficient to maintain essentially stable performance time (±0.1 s) over 15 intervals despite blood lactate concentrations that reached 10 mmol\(L^{-1}\) halfway through the session. In the Balsam et al. study, reducing the rest duration to 60 s only caused a 3–4% increase in 40-m time after 15 sprints, with similar blood lactate accumulation. However, reducing recovery to 30 s caused performance time to increase earlier and to a greater extent (12%). The more rapid and dramatic performance decline during repeated sprints when recovery was reduced to 30 s was not directly attributable to differences in blood lactate concentration, as blood lactate rose identically through 10 bouts for all three rest conditions. A blood lactate concentration of up to 10 mmol\(L^{-1}\) was not associated with a significant performance decline in repeated sprint bouts separated by 120 s of recovery. However, at the same 10 mmol\(L^{-1}\) blood lactate, sprint performance deteriorated when recovery duration was only 30 s. All these findings are consistent with accepted guidelines for high-intensity aerobic intervals being performed in the 5- to 10 mmol\(L^{-1}\) blood lactate range. Blood lactate concentrations in this range may be an indirect indicator that other intracellular ion disturbances can be restored within about 120 s. This may represent a practical demarcation between aerobic interval training and sprint training designed specifically to enhance anaerobic power and capacity.

While experienced endurance athletes are able to hold velocity constant over repeated work bouts, the perceived effort of achieving that velocity increases steadily from bout to bout. In this study and a previous one involving well-trained runners (24), we observed a linear increase in RPE through six 4-min work bouts (Fig. 3). After one 4-min work bout, RPE averages about 14–15 or “hard.” By the sixth and final bout, RPE has risen to 16–18 or “very hard” despite constant velocity. Extrapolating this linear increase in perceived exertion suggests that the subjects would have reached the same RPE that they reported at exhaustion during the maximal treadmill test within one to two more work bouts (RPE of 18–19). It appears that 30 min of work in the near \( \dot{V}O_{2\text{max}} \) range represents an upper limit for this type of interval training. Had the athletes in the present study been deceived such that after the planned six bouts they were asked to continue for a seventh or eighth 4-min work bout, it is likely that voluntary exhaustion would have occurred at blood lactate concentrations considerably below
the 12 mmol·L⁻¹ measured after a progressive maximal treadmill test to exhaustion. One important mechanism of both motor unit fatigue and increasing RPE during interval training of this type can be glycogen depletion (23).

If we extend the teleoanticipation concept to high-intensity intermittent exercise, then the selection of running intensity during the work periods can be viewed as a cognitive response to physiological feedback. The constantly increasing RPE experienced during interval training is merely an accelerated version of the upward drift in RPE observed in steady-state exercise at lower intensities. However, the pacing problem is arguably even more complex during intermittent exercise given the challenge of integrating both cellular and systemic fatigue rates and their recovery rates as represented by afferent feedback. Athletes extrapolate these perceptual signals early in an intermittent exercise situation, projecting forward to some goal distance or duration, and adjust intensity accordingly such that all bouts can be completed without an obligatory reduction in intensity. It is reasonable to expect that the pace chosen for an interval session is based on a combination of acute feedback from the present exercise bout and past experience from similar conditions. With this in mind, the athletes in the present study were more accustomed to performing interval bouts with recovery periods shorter than 4 min. It is possible that they underestimated their recovery during the 4-min recovery session and therefore chose a pace that was slower than necessary. This conjecture is supported by the fact that RPE tended to be slightly lower during the 4-min recovery interval session (Fig. 3). We also observed that athletes identified their running pace for the entire session early in the interval session, with little or no velocity adjustment made after the first one or two bouts of the six-bout interval session. Indeed, the 4-min recovery condition was the only one in which the average running velocity for the entire session was significantly higher than that achieved in the first interval bout (0.59 ± 0.45 km·h⁻¹ higher). Therefore, failure of the athletes to benefit from increasing recovery time from 2 to 4 min during self-paced interval training may have both peripheral and central explanations.

Analysis of HR responses during interval training highlighted two important patterns of response relevant to interval training prescription. First, HR drift occurs during interval training, just as in continuous exercise (Fig. 2). In the present group of well-trained athletes, HR drifted up about 12 bpm over the course of a 24-min cumulated period of work, whereas running velocity was essentially constant. Within the range studied here, increasing the recovery duration did not attenuate the magnitude of HR drift across the work periods. This expected HR drift should be taken into account if HR is to be used to guide intensity during aerobic interval training. Second, during rest between interval bouts, the rate of HR decline slows progressively. In the present study, HR recovered to 110–125 bpm by the end of the first rest period, dependent on recovery duration (active recovery). As the interval session progressed, the HR at the end of the recovery period drifted upward, more in the 1-min condition (from 125 to 148 bpm), but also in the 2-min (120–131 bpm) and 4-min recovery conditions (110–125 bpm). Despite the failure of HR to drop to the same low levels as the session progressed, athletes were able to maintain the same running velocity during later work periods. Unpublished data from our laboratory suggests that the slope of the initial fast phase of HR recovery rate is not significantly influenced by the cellular conditions around active muscle at the cessation of exercise (quantified as blood lactate concentration), but appears to be primarily mediated via central control mechanisms. Assuming HR recovery is not influenced meaningfully by skeletal muscle recovery, its usefulness as a tool for determining recovery duration during interval training is questioned.

CONCLUSIONS

Due to difficulties in relating absolute velocities to physiological intensity in many training situations, interval training sessions are often performed in response to a prescription combining work duration, recovery duration, and number of work bouts. The athlete’s achieved work intensity for the session represents the dependent variable in a multivariate equation. In this study, we manipulated the variable recovery duration in this equation. We observed that increasing recovery duration from 1 to 4 min actually had a minimal impact (2% increase) on running velocity during the work bouts. A 2-min recovery period was sufficient to achieve stable performance during high-intensity aerobic interval training. Physiologically, this finding is consistent with the rapid time course of several acute intracellular recovery processes after work cessation. Psychologically, the concept of teleoanticipation discussed in single bout or steady-state exercise scenarios seems to also be quite relevant to intermittent exercise. During intermittent exercise athletes perform rapid calculations of how close to their limits they can perform during each work bout, while sufficiently recovering during a subsequent rest period to enable repeated bouts of the same or higher absolute intensity. These teleoanticipatory calculations may be more accurate when athletes use shorter rest intervals or a rest interval duration with which they are very familiar.(13)

REFERENCES


