

UNIVERSITY OF WISCONSIN-LA CROSSE

Graduate Studies

SWIMMING PERFORMANCE IN RELATION TO TRAINING LOAD

A Manuscript Style Thesis Submitted in Partial Fulfillment of the Requirements for the
Degree of Master of Science

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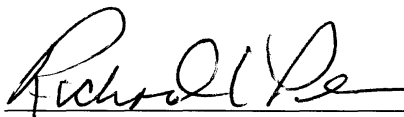
August, 2009

SWIMMING SPEED IN RELATION TO TRAINIG LOAD

By Eric Wojta

We recommend acceptance of this thesis in partial fulfillment of the candidate's requirements for the degree of Master of Science and Human Performance

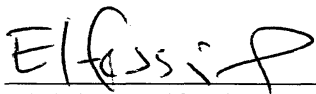
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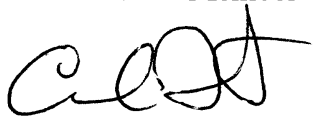
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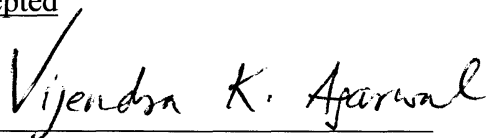


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ABSTRACT

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The amount and intensity of training a subject enters into will impact athletic performance. Previous studies have demonstrated that fitness and fatigue achieved during training will impact performance. This study compared the subject's performance in time trials to the subject's level of fitness minus the level of fatigue (Fit-Fat) as calculated for each subject. Twelve male and twenty-four female swimmers ($n = 36$) volunteered to participate in eleven weeks of varied intensity and duration training sessions while performing 100 yard time trials at the end of each training phase. Subjects' percent improvements on the time trial (NormTT) were compared to the Fit-Fat of each swimmer during each training phase. At the end of the seven week general endurance phase (GETT) a 0.205 correlation was observed between the two variables with $p = 0.229$. The increased loading phase (ILTT) yielded a 0.159 correlation with $p = 0.355$ while the decreased loading phase (DLTT) yielded a 0.201 correlation with $p = 0.254$. Subjects averaged during the GETT a Fit-Fat of -47.417 and a 2.563 percent faster NormTT. Average values during the ILTT were Fit-Fat of -80.028 and a 1.825 percent faster NormTT and during the DLTT a Fit-Fat of 220.861 with a 4.260 percent faster NormTT. Mean NormTT for the DLTT proved to be significantly faster than the mean NormTT for the GETT and ILTT ($p < 0.05$). The use of Fit-Fat in an attempt to predict a subject's percent improvement on performance proved not to be successful at a significant level ($p < 0.05$).

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INTRODUCTION

The goal in developing a seasonal training plan is to have each athlete achieve optimal performance at a predetermined competition, usually near the end of the season. To accomplish this, periodization methods are used in training. These methods involve mesocycles (4 to 6 week cycles) causing stress and fatigue designed to provoke biological adaptations to the training (1,2,3,4). At the end of this process a new mesocycle is introduced in which higher volume and/or higher intensity training is involved (e.g. progression). This process is continually repeated with the goal of increasing the athlete's fitness level. This will, in turn, heighten the level of performance for the athlete.

The process of progressing to higher training intensity and/or volume is not without possible pitfalls. One problem is that an athlete may fail to adapt to an increased training load by becoming fatigued, thus causing a poor performance. Quite often this poor performance will cause coaches to incorrectly believe that the athlete is not fit. This assumption will lead to an improper behavioral response by athletes and coaches, an increase in training. Ignoring necessary recovery during training can lead to cumulative fatigue over the course of time, and can ultimately result in the athlete developing a condition known as overtraining syndrome, (OTS) (3,5,6,7,8,9,10,11). Consequences of OTS can include: a) failure to improve on performance from early- to late-season; b) failure to improve on previous best times; c) consistent high levels of fatigue; d) elevated

resting heart rate; e) insomnia; f) weight loss; g) and over-use injuries (2,3,6,11,12,13,14). In order to avoid OTC a balance between fitness and fatigue must be achieved in the training program. Coaches are usually left with little more than their own experience and intuition to guide them in achieving this balance.

Fitness and fatigue, can be combined to gauge the impact training has on performance. Fitz-Clarke et al (14) provided a model that demonstrated as athletes training loads increased, the athletes level of fatigue outweighed their fitness. Athletes in this situation were said to have a negative predicted performance state (e.g. slower swimming times). Once the athlete has engaged in a period of decreased training load (i.e. recovery), the fatigue level will begin to dissipate. A high level of fitness and a low level of fatigue will allow an athlete to operate from a positive predicted performance state, resulting in a faster swimming performance. Improved swimming performance will occur when fitness outweighs fatigue. The athlete in this situation will be able to operate much closer to their level of peak performance because they do not have to deal with the consequences of training fatigue. In the model of fitness vs. fatigue there are measures to evaluate the effect that training has on performance.

The predicted performance of an athlete at any given time can be defined by the difference between that athlete's fitness and fatigue (3,4,15,16). The methodological problem is to quantify the training effect to represent an athlete's current amount of fitness and fatigue (Fit – Fat). One approach to quantifying the training load involves the product of time spent training (in minutes) and exercise intensity (the change in heart rate ratio while exercising) to give the overall training impulse (TRIMP) for that training session (16). An alternative model involves replacing heart rate as a marker of intensity

with the rating of perceived exertion (RPE) for the session (17,18). The product of the RPE and time of that training session calculate the session training load. The models involving heart rate and RPE are conceptually, but not numerically equivalent methods of quantifying training loads.

When seasonal training is completed, there are three possible performance outcomes; the athlete can be under-trained, over-trained, or trained for peak performance. The purpose of this study was to create a controlled observational period focusing on two aspects: a) monitoring subjects long and short term training load (fitness minus fatigue) and b) monitoring the subjects training load in relation to the impact it has on performance. The goal of this study was to document and relate increases in training load (the product of training time and RPE) with swimming speed in an applied setting with the intent of evaluating the impact of training load on performance.

To measure the impact training has on a performance, subjects Fit – Fat will be compared to subsequent time trials to see if there is a correlation between the two variables. This study will test to see if it is possible to predict a subject's performance solely from that subjects Fit – Fat score. It will be determined if swim coaches will be able to predict the amount faster or slower a subject will perform in the future compared to past performances from the amount and intensity of the training that subject has engaged in.

METHODS

Subjects

All 36 subjects (12 male and 24 female) in the study were members of the NCAA Division III University of Wisconsin - La Crosse swimming team. All subjects provided the researcher informed consent before engaging in the study and participation was purely on a voluntary basis. For the protection of human subjects, the University Institutional Review Board approved the study protocol. The researcher used no coercive behavior, and subjects were allowed to remove themselves from the study at any time.

Study Design

The study involved eleven weeks (79 days) of training during which the subjects completed three different training cycles of varying intensity and time of practice. Subjects kept a daily training log that documented the effort put forth during each training session by recording the rating of perceived exertion (RPE) and total time of the session. The training log was used to calculate the overall effect training load had on the subject's level of fitness and fatigue. Twice each week at the end of a standardized warm up each subject performed a maximal effort, one hundred yard timed swim. This time trial swim was used as a marker of performance on that day.

Data was analyzed for each subject three times during this study. The first measurement was at the end of the General Endurance period of this study (GETT), the second measurement during the Increased Training Load period (ILTT) and the third and final measurement at the end of the Decreased Training Load period (DLTT). The observations were chosen to be at or near the end of each of the three training periods to

give the subjects full opportunity to engage in the training protocol. GETT was chosen on day 46 so that the subjects would have at least six weeks of training in order to calculate an accurate level of fitness. ILTT was chosen on day 60 with the intent of placing the subjects in a negative Fit-Fat range where their fatigue level will outweigh their fitness level. DLTT was chosen on day 79 with the intent of placing the subjects in a positive Fit-Fat range where their fitness level will outweigh their fatigue level.

Training Protocol

During the eleven weeks of training the subjects engaged in three training cycles: General Endurance, Increased Training Load, and Decreased Training Load. The General Endurance period involved seven weeks to establish a baseline training level for each subject. Subjects then engaged in two weeks on Increased Training Load where session intensity and time were increased. The goal of this period was to put the subjects into a negative performance state where the benefit of training was outweighed by the fatigue of training. Training during this period was designed with the intent of the subjects achieving a negative Fit-Fat outcome. Then a two-week Decreased Training Load period involved the training load returning to baseline levels, thus allowing the participants to operate from a positive performance state where fitness outweighed fatigue. Training during this period was designed with the intent of the subjects achieving a positive Fit-Fat outcome.

Time Trials

On Tuesdays and Thursdays of each week during the study participants performed a standardized warm up provided in Appendix B. Directly following the warm up the subjects swam a 100-yard maximal effort time trial from the starting blocks in their primary stroke. The times for the swims were recorded to the nearest tenth of a second. These time trials continued for the length of the study and were used as the performance criterion to gauge the impact that training load had on performance.

Training Load Calculation

To calculate training load, each subject kept a daily training log. Recorded in this training log was the duration of each training session in minutes, followed by the rating of perceived exertion (RPE) for that session. The RPE was chosen from a 0 to 10 Borg scale provided in Appendix C (6,8,9). The daily training load was calculated by multiplying the training session time in minutes by the RPE value (Load for Training Session = RPE x session time). The weekly training load was then calculated by taking the mean of the daily loads of that week. The daily and weekly training load for each subject were logged along with a rolling six-week average training load to establish a current level of fitness for each subject. This rolling six-week average was used as a mean measure of the fitness (positive training outcome) of the subject and was calculated prior to each criterion performance. (Fitness = sum of training loads for the last 42 days \div 42). A seven day rolling average taken prior to each criterion performance will be used as an indicator of training fatigue (negative training outcome). This rolling average for fatigue was calculated for the training load seven days prior to each time trial.

(Fatigue = sum of training loads for the last 7 days \div 7). Rolling averages were used to accurately document the amount and intensity of training immediately leading up to the criterion performance. Averages for Fitness and Fatigue individually are positive as they document work that has been achieved (RPE x time).

STATISTICAL ANALYSIS

To allow for individual differences of subjects entering the study, time trials were normalized for each subject to be documented as a percentage faster or slower than a baseline level for each subject. This normalization process was instituted in order to appropriately measure how much faster or slower that subject has swam in comparison to how fast that subject swam as they entered into this study. The first three time trials for each subject (days 4, 9, and 11) were averaged to create a baseline mean performance for each swimmer. All subsequent time trials were normalized for each subject by recording each swim as a percent faster (positive value) or slower (negative value) than that subjects baseline mean performance. Normalized Time Trial (NormTT) values represent the percent faster or slower that subject's time was in comparison to their baseline time. Positive NormTT will represent the percent faster that subject swam and negative NormTT will represent the percent slower that subject swam in comparison to baseline levels. Fitness (last six week training load average) and fatigue (last seven day training load average) were documented for each subject prior to each Time Trial in order to calculate each subjects Fitness minus Fatigue (Fit-Fat) prior to each performance.

A Pearson Correlation was used to analyze data for each subject during each of the three training sessions to correlate Fit-Fat and NormTT. The first measurement was at the end of the General Endurance period of this study (day 46), the second measurement during the Increased Training Load period (day 60) and the third and final measurement at the end of the Decreased Training Load period (day 79). The means of NormTT for the three training sessions were analyzed using a Repeated Measure Design to identify if there were any significant differences between the mean values. Bonferroni

procedures were used in a Post Hoc analysis to locate where the significant differences occurred. Significance between the two variables was identified by Alpha level of 0.05.

RESULTS

In testing Fitness minus Fatigue (Fit-Fat) and percent faster or slower on the Normalized Time Trial (NormTT) it was found that a mild positive correlation occurred between the two variables but not at a significant level. In the General Endurance Training Phase these variables demonstrated a Pearson correlation of 0.205 with $p = 0.229$ (see Figure 1). During the Increased Loading Training Phase a Pearson correlation of 0.159 with $p = 0.355$ was demonstrated (see Figure 2). Data during the Decreased Loading Training Phase produced a Pearson correlation of 0.201 with $p = 0.254$ (see Figure 3).

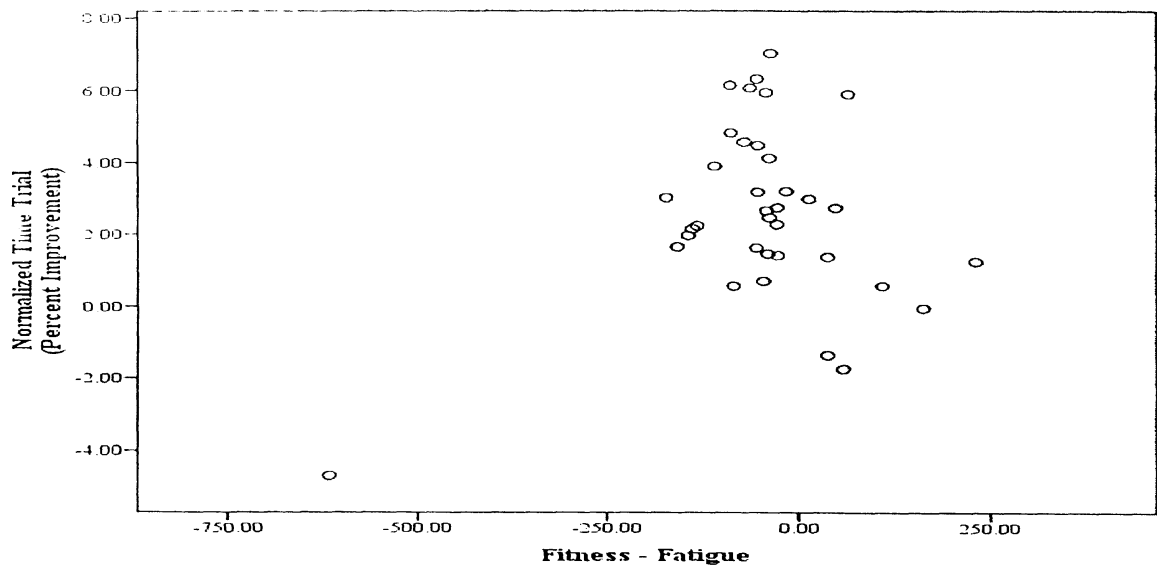


Figure 1. Percent Improvement on GETT

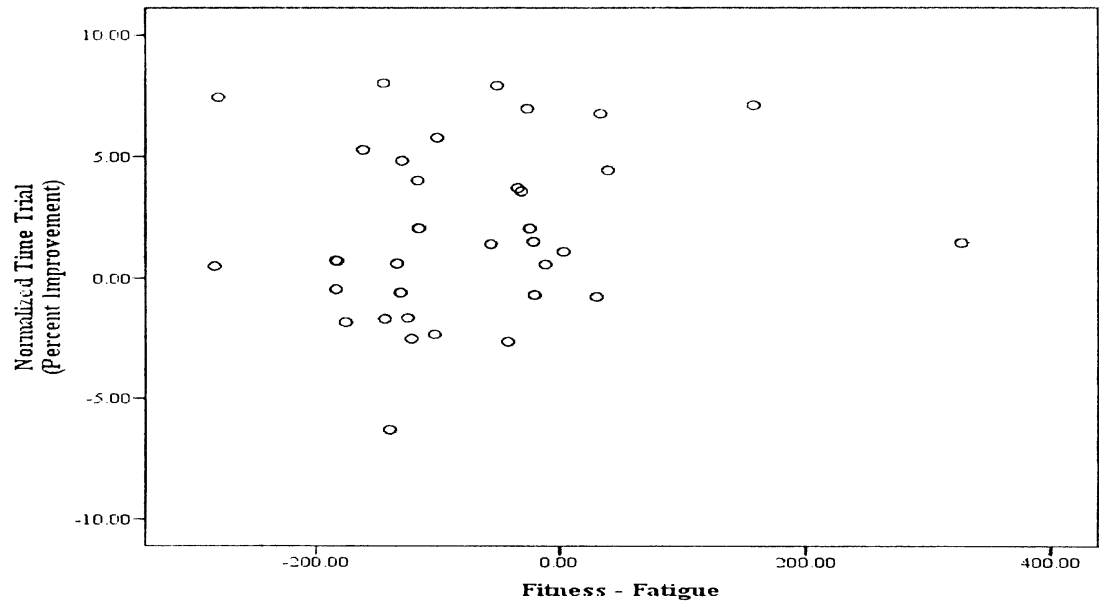


Figure 2. Percent Improvement on ILTT

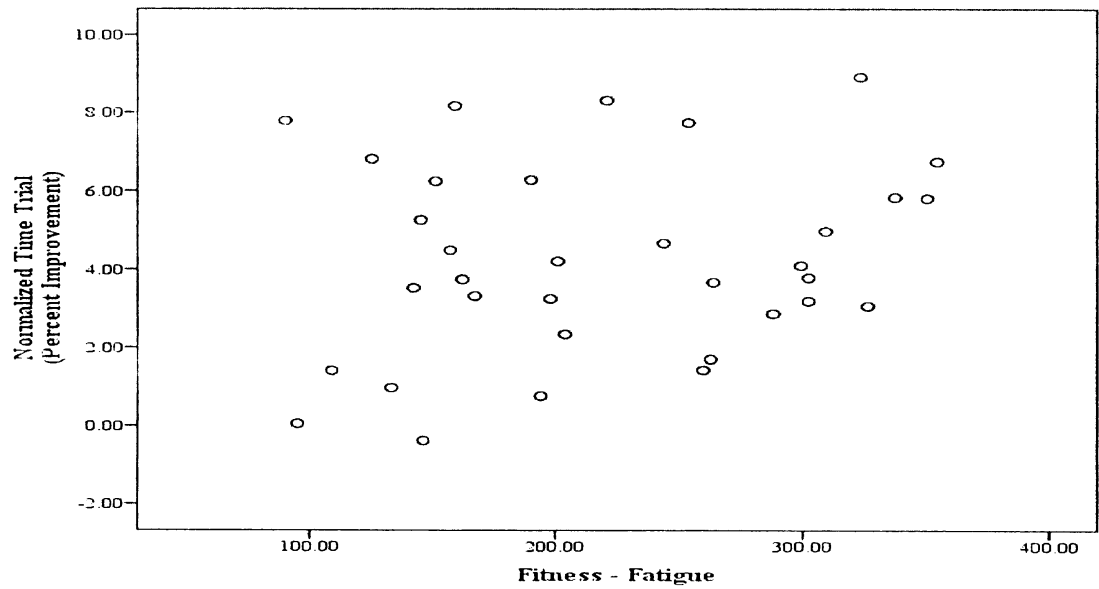


Figure 3. Percent Improvement on DLTT

As subjects Fitness minus Fatigue became more positive, the Normalized Time Trial seemed to become more positive, but not to a significant level to correlate the two variables.

During the General Endurance (GETT) Training Phase (day 46) subjects obtained a mean Fitness minus Fatigue level of -47.417 (duration of training session multiplied by session RPE) and achieved a 2.563 percent faster Normalized Time Trial (NormTT). Upper and lower bound values for NormTT during the GETT were 3.439 and 1.687 respectively with a standard error of 0.431. The Increased Loading (ILTT) Training Phase (day 60) produced a mean Fitness minus Fatigue level of -80.028 and a 1.825 percent faster Normalized Time Trial for subjects during this time. Upper and lower bound values for NormTT during the ILTT were 3.025 and 0.0625 respectively with a standard error of 0.590. Finally, the Decreased Loading (DLTT) Training Phase (day 79) produced a mean Fitness minus Fatigue level of 220.861 with a 4.260 percent faster Normalized Time Trial (see Table 1 and Figure 4). Upper and lower bound values for NormTT during the DLTT were 5.122 and 3.397 respectively with a standard error of 0.424.

Table 1. Mean Fit – Fat for the Three Training Sessions

	GETT	ILTT	DLTT
Fitness	425.11	551.694	486.222
Fatigue	472.528	631.722	256.361
Fit-Fat	-47.417	-80.028	220.861
NormTT	2.563	1.825	4.26

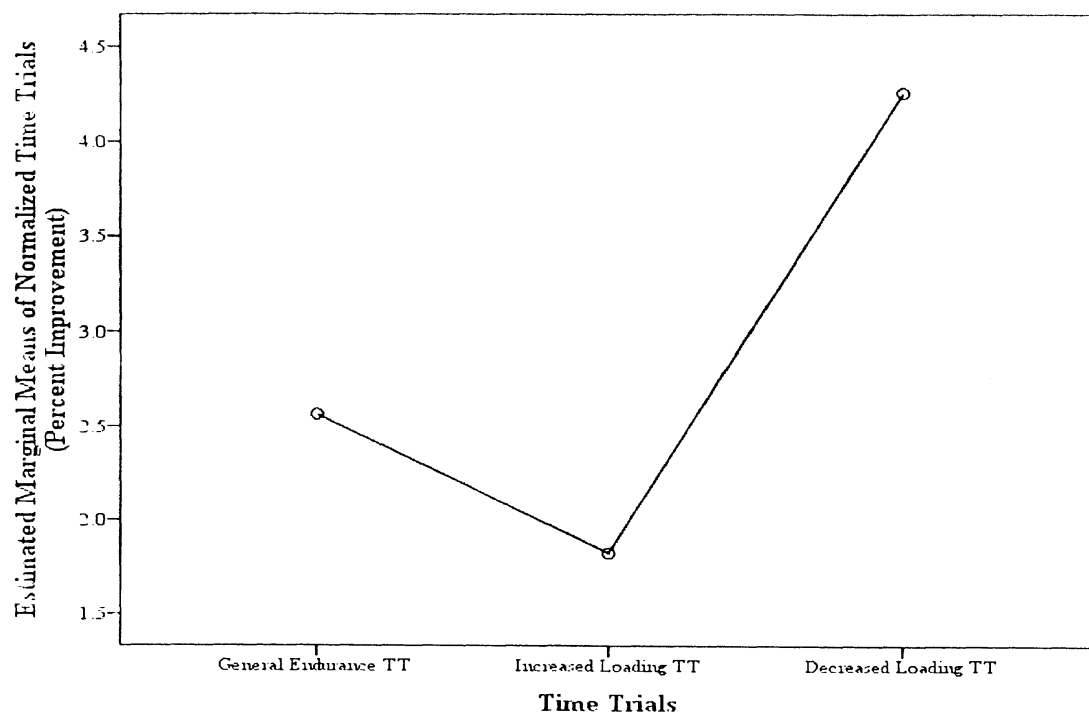


Figure 4. NormTT for the Three Training Phases

Mean NormTT for each of the three training sessions were analyzed using Repeated Measures Design to identify if significant differences existed. Tests of Within-Subjects Effects yielded that there were global differences in the mean NormTT for the three training sessions ($F = 8.332$, $P = .001$) with two degrees of freedom. Post Hoc analysis utilizing Bonferroni Procedures was used to identify those significant differences occurred between specific mean NormTT. Significant differences occurred between the mean General Endurance NormTT (GETT) and the mean Decreased Loading NormTT (DLTT) ($p < 0.05$) as well as between the mean Increased Loading NormTT (ILTT) and the mean DLTT ($p < 0.05$). No significant differences occurred between the means of GETT and ILTT (See Table 2).

Table 2. Mean NormTT

(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig. ^a	95% Confidence Interval for Difference ^a	
					Lower Bound	Upper Bound
GETT	ILTT	.738	.469	.376	-.445	1.922
	DLTT	-1.697*	.595	.022	-3.196	-.197
ILTT	GETT	-.738	.469	.376	-1.922	.445
	DLTT	-2.435*	.741	.007	-4.304	-.566
DLTT	GETT	1.697*	.595	.022	.197	3.196
	ILTT	2.435*	.741	.007	.566	4.304

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

*. The mean difference is significant at the .05 level.

DISCUSSION

The protocol of this study was to have the subjects engage in three different training phases (General Endurance, Increased Loading, and Decreased Loading) while monitoring the subjects performance during these three phases. The design of this study was achieved by the subjects self reported mean fitness levels for each training phase. The mean fitness levels during each of the training phases were; GETT = 425.110, ILTT = 551.694, and DLTT = 486.222. It was evident that the subjects mean fitness level went up during the Increased Loading phase and then went down during the Decreased Loading phase. These changes in training levels are consistent with many swim coaches seasonal training programs that build training volume and intensity throughout the season in order to reduce that volume and intensity at the end of the season when the swimmers are to peak for a competition.

Of particular interest in this study is the fact that the subjects' mean NormTT was positive for all three training phases. Subjects in the GETT showed a 2.563 percent faster time, swimmers in ILTT showed a 1.825 percent faster time, and swimmers in DLTT showed a 4.260 percent faster time in relation to baseline time trials. In general, it appears that swimmers in all three training periods in the study benefited from the positive effect of training (increased fitness levels) in relation to their baseline time trial. On average swimmers went faster weeks into this training plan than they did at the beginning of the training plan, which reinforces that there is benefit to training. How coaches continue to modify training programs in order to maximize the benefits of increased fitness levels while minimizing the negative aspects of fatigue will continue to be involved in the art and science that is coaching.

During the course of this study, general trends were seen with the subjects as a group, but using specific data to predict one subject's percent improvement on performance by using Fitness minus Fatigue (Fit – Fat) proved not to be successful. All three training phases showed a mild positive correlation between Fit-Fat and NormTT, though none of these correlations between the two variables was at a significant level. The three different training sessions had p levels of 0.229, 0.355, and 0.254 for Fit-Fat as a predictor of NormTT. These p levels are well outside the acceptable significant range of $p < 0.05$. The idea of a coach using a subjects Fitness minus Fatigue as a predictor of the percent faster or slower (NormTT) that subject will swim in their next performance appears not to work specifically for each swimmer in the current model. The lack of correlative data between Fit-Fat and NormTT suggests that changes in Fit-Fat will not yield equally measurable changes in performance for all swimmers.

Although this model was unsuccessful in using the subjects Fit-Fat as a predictor of the percent faster or slower an individual athlete will swim, it does provide reliable feedback for training a group. Analyzing the mean data for the group of 36 swimmers during the three training periods shows that swimmers had a negative Fit-Fat during GETT and ILTT (-47.417 and -80.028) and a positive Fit-Fat during DLTT (220.861). Normalized Time Trial results during each of the three training phases showed on average subjects swam faster than the baseline time trial. This can be concluded because the means were positive for all three training phases.

In relation to baseline time trials, swimmers in the GETT showed a 2.563 percent faster time, swimmers in ILTT showed a 1.825 percent faster time, and swimmers in DLTT showed a 4.260 percent faster time. It appears that during the GETT swimmers

benefited from the high level of fitness and were minimally affected by the high level of fatigue. During the ILTT, the swimmers NormTT was positive (1.825) but slower than the GETT (2.563) despite the fact that the mean fitness level was higher during ILTT than during GETT (see Figure 1). One possible explanation for the slower time trial might be that the subjects had a mean higher level of fatigue in ILTT (631.722) as opposed to the fatigue in GETT (472.528). Of the three training periods, the DLTT had the smallest level of fatigue and was in the middle for mean fitness level yet produced the significantly fastest time trial. Subjects averaged the most positive Fit-Fat during the DLTT which consequently is where the subjects mean NormTT was significantly faster than in the other training sessions. It appears that if swimming fast is the desirable outcome, the swimmer should strive for the highest level of fitness possible while producing the smallest amount of fatigue (i.e. the most positive Fit-Fat).

Often swim teams engage in a “drop taper” where swimmers reduce training load for a week or less. Sprinters have been known to engage in a taper phase that can last up to four weeks. Future suggestions for studies could involve testing whether a longer or shorter recovery period would impact swimming performance. In this study performance was measured after two weeks of decreased loading, but further studies could examine the performance changes after one, three or four weeks of decreased loading.

It is not uncommon to hear an athlete say that they are sore from a workout the day before. Future studies could be conducted to determine if the training that a swimmer engaged in the day prior to a performance would significantly impact that performance. In this study a seven day rolling average was used as the measure of

fatigue, but future studies could include research on whether a more sensitive measure such as two day fatigue along with weekly fatigue would impact swimming performance.

In conclusion, coaches should not attempt to use the Fit-Fat model explored in this study to predict a swimmer's time in an upcoming race on an individual basis. The Fit-Fat model as used in this study proved to be unreliable as a predictor of swimming improvement on an individual basis. Coaches may benefit from this model to get a generalized idea as to when the team as a group is in a positive predicted performance state. It was found that of the three training sessions, the session that had the highest mean Fit-Fat level was also the session that had significantly faster mean performance (the DLTT having the most positive mean Fit-Fat was also the fastest mean time trial). In fact the DLTT was the only mean time trial that was significantly faster than the other time trials. The goal of a seasonal training plan for a swim team would be to have your swimmers be at their fastest at the end of the season. This improvement in performance would happen when they benefit from the positive aspects of a high fitness level while keeping the debilitating effects of fatigue to a minimum. Coaches continue to modify seasonal training plans from year to year in order to produce optimal athletic performance at a desired time. Informal studies such as this have been and will continue to go on for years to come as coaches evaluate what aspects of training produced the desired performance results. Any conclusive results from future studies on this topic would be of great benefit to athletes and coaches on their continued journey to achieve optimal performance.

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APPENDIX A
INFORMED CONSENT

INFORMED CONSENT

PERFORMANCE MEASURED IN SWIMMING SPEED IN RELATION TO TRAINING LOAD

I give my informed consent to participate in this study of how training load will affect swimming performance. I consent to presentation and publication or other dissemination of study results so long as the information is anonymous so that no personal identification can be made.

- 1) I have been informed that although a record will be kept of my having participated in the study, all experimental data collected from my participation will be identified by number only.
- 2) I have been informed that my participation in this study will involve my keeping a daily training log, documenting my time involved in training (in minutes) and my rating of perceived exertion (RPE).
- 3) I have been informed that my participation in this study will involve a 100 yard all-out effort for time in my major stroke twice each week for the duration of the study. This is not any different than the training that the swim team would engage in.
- 4) I have been informed that my participation in this study will involve my partaking in 11 weeks of training. This is not any different than the training that the swim team would engage in.
- 5) I have been informed that there are no known or anticipated risks involved in my participation in this study.
- 6) I have been informed that there are not "disguised" procedures in this study. All procedures can be taken at face value.
- 7) I have been informed that I am free to withdraw from the project at any time without penalty.
- 8) I have been informed that participation in this study will have no affect on my varsity status on the University of Wisconsin at La Crosse swim team.

- 9) I have been informed that if I have any questions regarding this study, I can contact Dr. Richard Pein, Associate Professor in the Department of Exercise and Sport Science, UW-La Crosse and director of this study, telephone: (608) 785-8185.
- 10) I have been informed that questions regarding the protection of human subjects may be addressed to Dr. Roderick Duquette, chair of UWL-Institutional Review Board for protection of human subjects, telephone: (608) 785-8161.
- 11) I have read all the above and I have been informed what is expected of me and I consent to participate in this study.

All my questions regarding this study have been answered to my complete satisfaction. I therefore voluntarily accept to be tested, and I know that I may withdraw from the study at any time without penalty.

Signed: _____

Date: _____

Researcher: _____

Date: _____

APPENDIX B
PRE-TIME TRIAL WARM-UP

PRE-TIME TRIAL WARMUP

200 Reverse IM Order

Fly is dolphin kick – no arms

5 x 100 IM on 2:00

1 - all drill

2 - 50 drill / 50 swim

3 - 50 swim / 50 drill

4 - 25 drill / 75 swim

5 - swim

Drills

Fly- one arm

Back- pause

Breast- 2kick/pull

Free- dog paddle

5 x 100 free on 1:35

Pull no bubbles!

1200 yards

APPENDIX C
RATING OF PERCEIVED EXERTION
BORG SCALE

RATING OF PERCEIVED EXERTION – BORG SCALE

Rating	Verbal Description
0	Rest
1	Really Easy
2	Easy
3	Moderate
4	Sort of Hard
5	Hard
6	
7	Really Hard
8	
9	Really, Really Hard
10	Just Like My Hardest Race

APPENDIX D
REVIEW OF RELATED LITERATURE

REVIEW OF RELATED LITERATURE

Introduction

A large amount of research has been conducted on the how the human body physiologically responds to varied types of training. In particular, much research has been performed measuring changes in heart rate, lactate production, blood pressure, and VO_2 max during training sessions in athletes (4,8,9,19,24). While documenting the athlete's biological responses to training is commonplace, evaluating the effect that training has on a performance outcome is not common.

The purpose of this literature review was to first establish a reliable method of quantifying training. Secondly, the review will identify a protocol for reliable measurement of the performance outcomes. Thirdly, the review sought to identify methods that document the impact that training has on the performance outcomes.

Methods for Quantifying Training

The common thought is that the human body will adapt after a bout of training and improve working capacity. Coaches are left with intuition and experience to guide them as to balance how much work the athlete should engage in during a workout bout. In modeling studies, researchers often quantify training or workout bouts in order to objectively analyze the training (1,3,20,21,22). Variables used in Morton et al., to quantify a bout of training were the duration of the training session and the change in heart rate or average heart rate during that training session (22). The product of the two variables, duration and average heart rate, are multiplied by a non-linear metabolic adjustment to create an arbitrary unit called the training impulse or TRIMP (2,21,22).

This gives the researcher a quantitative amount of training dose that has occurred during that training session.

Foster et al. (6,7,9) developed a system of quantifying a bout of training by replacing the heart rate in the TRIMP model with the rating of perceived exertion (RPE) of the training session. The RPE of the entire workout session was chosen from a 0 to 10 Borg scale and multiplied by the duration of the entire workout session thus producing the session training LOAD. Using this technique you achieve a numerical value that represents the impact of the training session. Using this technique, the researcher can combine training intensity and training volume into a single number. This opens the possibility to examine the quantitative relationship between training and performance.

Protocol for Measurement of Outcomes

When working with athletes that are training in the anaerobic and aerobic systems, researchers use a variety of markers to document the body's capacity for training. Twelve male competitive cyclists during a four-week program of high intensity cycling, each subject engaged in a VO_2 max test, a timed ride to fatigue, and forty-kilometer time trial. Heart rates (HR) were monitored throughout the training sessions and all subjects completed a profile of moods state (POMS) inventory to detect psychological changes that may have been associated with the interval-training program (16). Time trials along with laboratory tests were the measures of outcomes in this study.

Methods Documenting the Impact of Training on Performance

During training in a competitive season for eight male cross country and five male swimmers samples were obtained of venous blood, heart rate (HR), and blood pressure (BP) after 15 minutes supine rest. The samples were analyzed for cortisol, total testosterone, free testosterone, and creatine kinase. Blood samples were obtained along with heart rate (HR) and rating of perceived exertion (RPE) during fixed distance workouts either running or swimming. Information was documented during the length of the training season of seventeen weeks. During the taper or rest period of the season, it was found that total testosterone and free testosterone increased while creatine kinase decreased. This suggested that total testosterone, free testosterone, and creatine kinase might be effective markers for monitoring training and overtraining in athletes (4). This also provided a framework of evaluating the effect of an extended training session for swimmers. These are reliable methods in evaluating training, but are not feasible to practice in an applied setting on a daily basis for monetary and time constraints.

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