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Graduate Studies

# Blood Lactate Clearance as a Measure of Recovery Using NormaTec Boots

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Fulfillment of the Requirements for the Degree of Master of Science in Clinical Exercise Physiology

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BLOOD LACTATE CLEARANCE AS A MEASURE OF RECOVERY USING NORMATEC BOOTS

By Riley O'Connor

We recommended acceptance of this thesis in partial fulfillment of the candidate's requirements for the degree of Master of Science in Clinical Exercise Physiology.

The candidate has completed the oral defense of the thesis.

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ABSTRACT

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The NormaTec Pulse 2.0 Recovery System is a recovery modality that has gained popularity amongst athletes recently. The purpose of this research was to compare blood lactate (BLa) clearance with the NormaTec Pulse 2.0 Recovery System compared to active and passive recovery. Fourteen subjects performed a $VO_2$max test on a cycle ergometer, which was used to find peak power output (PPO) and ventilatory threshold (VT). The subjects then performed three Tabata workouts immediately followed by a 30-minute recovery period (NormaTec, active, passive), in random order. Blood lactate clearance for both the NormaTec and active recovery conditions was significantly faster than passive recovery at the 5, 10, 20, 25, 30-minute measurement periods ($p<0.05$). Active recovery cleared BLa significantly faster than NormaTec at the 15, 20, 25, 30-minute measurement periods. There was no significant difference between active recovery and NormaTec within 10-minutes. On both the TQRS and VAS recovery questionnaires, subjects felt significantly more recovered immediately following the active recovery compared to the passive and NormaTec recovery conditions. The NormaTec Pulse 2.0 Recovery System was more effective at clearing BLa than passive recovery, but after 10 minutes is not as effective as active recovery.

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# INTRODUCTION

An athlete's ability to maximize their training is at least partially based upon their ability to fully recover between consecutive training sessions. Recovery is important because it is the period where all exercise-induced adaptations occur (Barnett, 2006). Recovery periods can be broken down into three distinct phases. The shortest period of recovery is between consecutive repetitions within a set of exercises. The second period is short-term recovery between sets, which could be the time between resistance sets or interval bouts. The third period is the recovery period between workouts, which has received the most focused research.

One of the measures used to gauge the speed of recovery is blood lactate (BLa) clearance. Although there is no causative relationship between BLa and fatigue, BLa clearance can be used as an indirect measure for the build-up and clearance of metabolites associated with fatigue. Active recovery has been shown to be the most effective method of BLa clearance (Monedero & Donne, 2006). Active recovery is the use of submaximal exercise following prior strenuous exercise, which increases blood flow and allows for the re-oxygenation of blood through increased alveolar gas exchange (Crowther, Sealey, Crowe, Edwards, & Halson, 2007). Previous studies have shown that performing active recovery at or near lactate threshold is the most efficient way of clearing BLa (Greenwood, Moses, Bernandino, Gaesser, & Weltman, 2008; McLellan & Skinner, 2008; Baldari, Vidiera, Madeira, & Guidetti, 2004). Not only has active recovery at lactate threshold been linked to BLa clearance, but it has also been shown to improve subsequent performance (Greenwood et al., 2008).

Intermittent pneumatic compression (IPC) devices have been a fairly recent recovery modality used amongst athletes to possibly accelerate their recovery. Intermittent pneumatic compression devices are typically worn on the extremities and incorporate chambers that are sequentially inflated and deflated. The pressure gradient created by the compression collapses the lumen of the vessel, pushing the blood toward the heart, which facilitates venous return (Khanna & Maffulli, 2008).

NormaTec produces a recovery modality called the Pulse 2.0 Recovery System (NormaTec, 2019). The Pulse 2.0 Recovery System consists of inflatable compression sleeves worn on the extremities; most often, it is a boot that encloses the foot to upper thigh. A series of compartments in the boot inflate sequentially from distal to proximal and remain pressurized until three compartments, or zones, are inflated (Northey, Rattray, Argus, Etxebarria, & Driller, 2016). The IPC system is intended to mimic the body's normal physiological processes ("biomimicry"), which increases venous return by applying pulsing compression, distal release, and gradients (NormaTec, 2019). NormaTec claims that it's Pulse 2.0 Recovery System accelerates the body's ability to passively clear metabolites, namely BLa, faster than passive recovery.

Many of the recovery modalities commonly used by athletes do not have extensive research supporting their effectiveness. Research on the ability of IPC's to effectively accelerate BLa removal is inconclusive. Several studies have shown various IPC devices to be better at BLa removal than passive recovery (Stetter, 2013; Martin, Friedenreich, Borges, & Roberts, 2015), while others have not (Keck, Cuddy, Hailes, Dumke, & Ruby, 2015; Overmayer & Driller, 2018; Marcello, Fortini, & Greer, 2019).

The purpose of this study was to evaluate BLa clearance following usage of the NormaTec Pulse 2.0 Recovery System in comparison to passive and active recovery.

## METHODS

### Subjects

Fourteen apparently healthy college students between 20-27 years of age from the University of Wisconsin- La Crosse were recruited for this study. Subjects were required to be highly fit (i.e., currently exercising at least five times per week for at least 30 minutes) and could not have had any lower extremity or back injuries within the last six months. Each subject completed a PAR-Q to screen for cardiovascular and orthopedic contraindications to exercise. Eligible subjects provided written informed consent before undergoing any testing procedures. The study was reviewed and approved by the University of Wisconsin–La Crosse Institutional Review Board for the Protection of Human Subjects.

### Procedures

Initially, each subject completed a maximal cycle ergometer test to determine maximal oxygen consumption ($VO_2max$), maximal heart rate (HRmax), ventilatory threshold (VT), and peak power output (PPO). The $VO_2max$ test was performed on an electronically-braked cycle ergometer (Lode B.V., Groningen, Netherlands). The test began at 25 W for 3 minutes and power output (PO) was increased by 25 W every minute until volitional fatigue. Respiratory gas exchange was measured using a mixing chamber based, open-circuit spirometry system (AEI Technologies, Naperville, IL). The gas analyzers were calibrated before each test using a reference gas mixture (16.02% $O_2$ and 4.00% $CO_2$) and room air (20.93% $O_2$ and 0.03% $CO_2$) and the pneumotac was calibrated with a 3 liter syringe.  Heart rate was measured every minute using radiotelemetry (Polar

Vantage XL, Polar Instruments, Port Washington, NY) and ratings of perceived exertion (RPE) were assessed each minute using the 6-20 Borg Scale (Borg, 1982). Maximal heart rate was determined as the highest heart rate observed during the test. Ventilatory threshold was determined using a combination of the V-slope and ventilatory equivalent methods (Foster & Cotter, 2006). Ventilatory threshold was defined as when $VCO_2$ increased disproportionately to $VO_2$ and when $VE/VO_2$ increased relative to $VO_2$, without $VE/VCO_2$ increasing.  Oxygen consumption was summated every 30 seconds, and the highest 30-second value was accepted as $VO_2$max value. Peak power output was defined as the highest PO recorded during the test.

Following the $VO_2$max test, subjects reported to the Human Performance Laboratory to perform a Tabata training session on a cycle ergometer. Initially, subjects warmed up for 5 minutes at a self-selected pace. They then completed the Tabata workout. The Tabata workout consisted of 20 seconds of work at a PO calculated to be 125% of PPO from the maximal cycle ergometer test, paired with 10 seconds of unloaded pedaling (50 Watts), for a total of 8 sets, or 4 minutes (Farland et al., 2015). Following each of the three Tabata workouts, the subjects continued cycling for 3 minutes at a self-selected pace as a cool-down. Following the cool-down, subjects were randomly selected to recover using either passive recovery, active recovery, or the NormaTec Pulse 2.0 Recovery System for 30 minutes (NormaTec Pulse 2.0 Recovery System, NormaTec, Watertown, MA). The passive recovery modality was performed while sitting in a reclined position with the feet elevated. The NormaTec recovery condition was performed in the identical position as the passive recovery, except subjects wore the NormaTec Pule 2.0 Recovery System and the maximal setting was used for all subjects (setting 7). The active recovery was performed on the cycle ergometer at a PO calculated to be 10% below the subject's VT. Blood lactate was measured before exercise, immediately after the cool-down, then in five minute increments post-exercise (5-,10-,15-,20-,25-, 30-minutes) using a capillary blood sample (Accusport Lactate Analyzer, Accusport, Hawthorne, NY). In subsequent testing sessions, separated by at least 72 hours, subjects completed the other two conditions, in random order.

Subjects were also required to complete two different recovery questionnaires following each recovery condition. Recovery was quantified visually by having subjects place a mark on a 10-cm Visual Analog Scale (VAS), with verbal anchors at 0 cm (not recovered at all) and 10 cm (fully recovered). The marks distance from the left were quantified as a percentage of the line length (Hoffman, Badowski, Chin, & Stuempfle, 2016). The subject's recovery was also quantified using the 6-20 Total Quality Recovery Scale (TQRS). On the TQRS scale, a rating of 6 represents very, very poor recovery whereas a rating of 20 represents very, very good recovery.

**Statistical Analaysis**

Basic descriptive statistics were used to summarize the subject's physical characteristics, as well as the BLa responses following the Tabata workout and throughout each recovery session. Repeated measures ANOVA was used to compare the changes in BLa clearance across time and between recovery conditions. Tukey's post-hoc tests were used to detect pairwise differences. Alpha was set at $p < .05$ to achieve statistical significance. All data are presented as mean ± standard deviation.

## RESULTS

Fourteen subjects completed the protocol. One subject dropped out of the study prior to completing all of the trials due to an orthopedic injury unrelated to the study protocol. The descriptive statistics of the 14 subjects who completed the study are presented in Table 1.

Table 1. Descriptive characteristics of subjects (N=14).

| | | |
|---|---|---|
| Age (yr) | 23.2 ± 1.76 | 20 - 27 |
| Height (cm) | 176.8 ± 6.76 | 165 - 188 |
| Weight (kg) | 84.6 ± 11.33 | 71 - 106 |
| $HR_{max}$ (bpm) | 188 ± 9.3 | 168 - 203 |
| VT (watts) | 132.1 ± 22.85 | 100 - 175 |
| $VO_2max$ (ml $O_2$/kg/min) | 47.0 ± 6.48 | 35.9 - 56.4 |
| PPO (watts) | 289.3 ± 25.41 | 250 - 325 |

Blood lactate values at each time point for each of the three recovery modalities are presented in Table 2 and Figure 1, respectively. Blood lactate clearance for both the NormaTec and active recovery conditions was significantly faster than passive recovery at the 5, 10, 20, 25, 30-minute measurement periods. Active recovery cleared BLa significantly faster than NormaTec at the 15, 20, 25, 30-minute measurement periods. There was no significant difference between active recovery and NormaTec at the 5 and 10-minute time points.

Table 2. Blood lactate values for the Passive, NormaTec, and Active recovery conditions.

| | Pre | Post | 5 | 10 | 15 | 20 | 25 | 30 |
|---|---|---|---|---|---|---|---|---|
| Passive | 1.6 ± .64 | 14.4 ± 2.46 | 13.9 ± 3.03 | 12.7 ± 3.26 | 11.0 ± 3.14 | 9.6 ± 3.04 | 8.7 ± 2.78 | 7.4 ± 2.67 |
| NormaTec | 1.4 ± .43 | 14.6 ± 2.43 | 12.6 ± 2.45[a] | 11.2 ± 2.63[a] | 10.1 ± 2.35 | 8.4 ± 2.16[a] | 7.4 ± 2.03[a] | 6.3 ± 1.81[a] |
| Active | 1.6 ± .68 | 14.4 ± 2.10 | 12.8 ± 2.13[a] | 10.5 ± 2.69[a] | 8.4 ± 2.80[ab] | 6.9 ± 2.32[ab] | 5.6 ± 2.39[ab] | 4.5 ± 1.94[ab] |

[a] Significantly lower than Passive recovery (p<.05).
[b] Significantly lower than NormaTec recovery (p<.05).

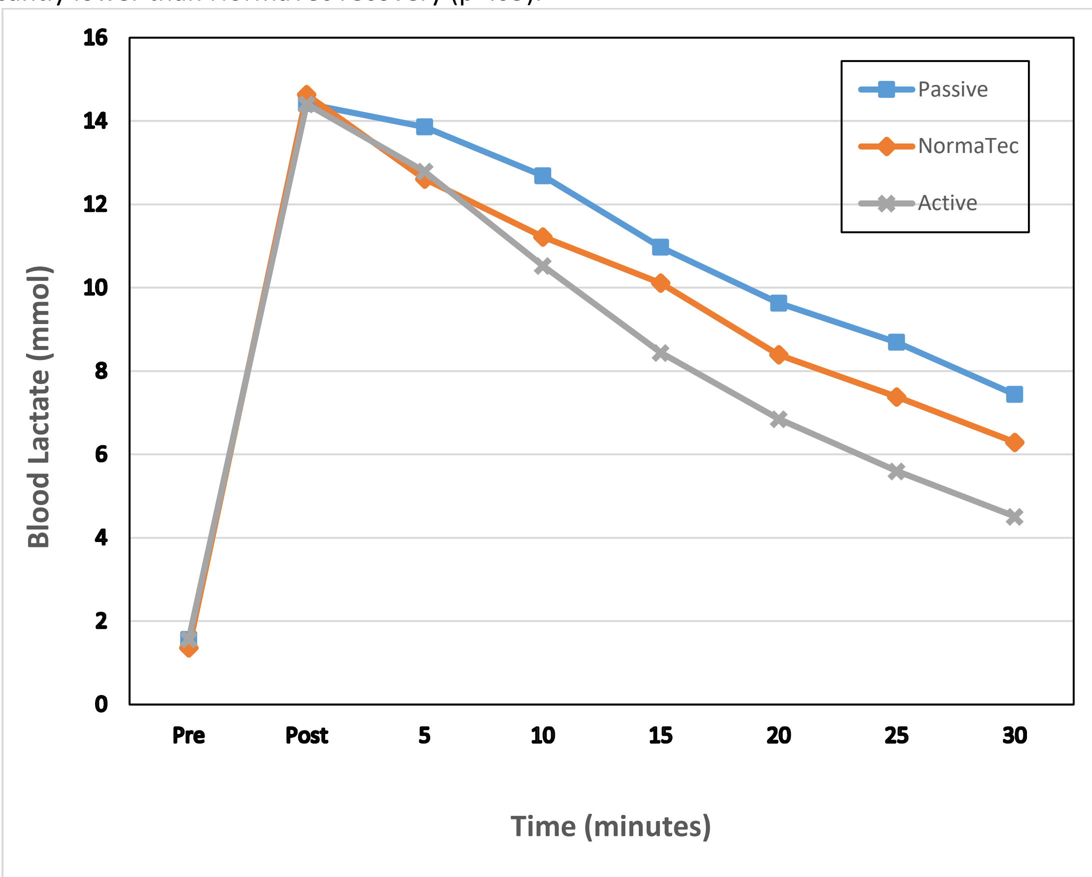


Figure 1. Blood lactate clearance between the Passive, NormaTec, and Active recovery conditions.

Data for the two recovery scale questionnaires (TQRS and VAS) between the three different recovery modalities are presented in Table 3. On both the TQRS and VAS recovery questionnaires, subjects felt significantly more recovered immediately following the active recovery compared to the passive and NormaTec recovery conditions.

Table 3. Recovery scale scores immediately following recovery period (Post) with Passive, NormaTec, and Active recovery strategies.

| | | Post |
|---|---|---|
| TQRS | | |
| | Passive | 14.8 ± 2.61 |
| | NormaTec | 16.0 ± 2.31 |
| | Active | 16.6 ± 1.56[a] |
| VAS | | |
| | Passive | 6.6 ± 1.77 |
| | NormaTec | 7.2 ± 1.26 |
| | Active | 8.0 ± 1.05[a] |

[a] Significantly greater than Passive Recovery ($p<.05$).

## DISCUSSION

The main purpose of this study was to evaluate BLa clearance using the NormaTec Pulse 2.0 Recovery System compared to passive and active recovery. It was found that both NormaTec boots and active recovery cleared BLa significantly faster than passive recovery over a 30-minute recovery period. During the first 10-minutes of recovery, there was no difference in BLa clearance between the NormaTec boots and active recovery. However, from the 15-minute measurement point onward, active recovery was more effective at clearing blood lactate than the NormaTec boots.

These findings are consistent with results from other studies. Hanson, Stetter, Li, and Thomas (2013) had female student-athletes complete a Wingate Test followed by a 20-minute recovery session. Comparing the same three modalities, they found that using an IPC device was more effective at clearing BLa than passive recovery and just as effective as active recovery. The use of the NormaTec boots in our study was just as effective at clearing BLa for the first 10 minutes of the recovery period, but after 10 minutes, active recovery cleared BLa significantly faster than the NormaTec boots. Martin, et al. (2015) also compared the rate of BLa clearance between IPC devices and passive recovery. They had subjects complete two Wingate Tests followed by 30-minutes of treatment. They found that IPC devices cleared BLa significantly faster than passive recovery

Increased clearance rate of BLa with active recovery is a result of the muscle pump increasing venous return, which would facilitate an increased blood flow to the working muscles (Monedero & Donne, 2000). This increase in blood flow would help to distribute the lactate more quickly to the rest of the body, so it could be metabolized by muscles. Oxidative muscle fibers are designed to oxidize lactate and use it as a fuel source, which is the primary method we hypothesized for increases in BLa clearance with active recovery. Although, glycolytic tissue also has the ability to metabolize lactate through its conversion to glycogen (Gladden, 2000). Similarly, the faster BLa clearance with the NormaTec boots is most likely due to an increased venous return, consequent to the sequential, pulsating compression provided by the boots. It has previously been shown that both low and high pressure pneumatic compression can increase venous return velocity (Malone, et al., 1999), which would increase blood flow to other tissues in the same manner as active recovery. Why active recovery resulted in faster BLa clearance than the NormaTec boots after 10 minutes can only be speculated upon. It is plausible that because the muscles of the leg were still working relatively hard (i.e., at 90% of VT), lactate could have been used as a fuel source which would remove it from the blood stream more quickly. During the NormaTec recovery period, subjects were not exercising, thus muscle metabolism was relatively low (Zurlo, Larson, Bogardus, & Ravussin, 1990).

Subjectively, based on the results of the TQRS and VAS questionnaires, subjects only felt more recovered immediately following the active workout. There was a trend for subjects to feel more recovered immediately after the NormaTec condition, but it was not statistically significant. These results are in agreement with a study by Hoffman, et al. (2016). They had subjects complete 20 minutes of IPC recovery following an extensive run. They found that the IPC recovery gave immediate subjective benefits compared to passive recovery.

The results of this study have several limitations. Due to the use of only young healthy recreationally active certain age the results have limited application for older individuals or females. Also, further research could be done using elite athletes and comparing blood lactate values using the same three modalities. Another limitation of this study was that we used a single, high-intensity exercise bout in order to accumulate BLa quickly. Future research could utilize different exercise protocols to accumulate BLa in subjects and see if that alters the subjective benefits of the different recovery modalities. Finally, this study used the highest pressure setting (Setting 7) on the NormaTec system, in an attempt to maximize results. In practical terms, individuals who purchase and use the NormaTec system may use lower settings, which could influence results.

# CONCLUSION

The results of this study indicate that the NormaTec Pulse 2.0 Recovery System is an effective recovery modality, at least in the terms of BLa clearance, when compared to passive recovery. It also indicates that the NormaTec Recovery System is as effective as active recovery, which is the gold standard for BLa clearance, in the first 10-minutes following an intense exercise session. Blood lactate clearance could be an indicator of increased blood flow to damaged muscles, which could decrease time needed for recovery.

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# APPENDIX A

# INFORMED CONSENT

Informed Consent

Effects of Recovery Modalities on Blood Lactate Clearance and Performance

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1. Introduction and Purpose of the Study

The subject will perform a maximal test on the cycle ergometer, which will be used to determine peak power output. At least 24 hours after the initial maximal test, the subject will be asked to perform a Tabata workout followed by a 30-minute recovery period. The tabata workout will consist of a 5-minute warm-up followed by eight sets of 20-seconds of maximal exertion and 10-seconds unweighted pedaling. The maximal exertion stages of the tabata workout will be performed at 125% of the highest recorded power output during the initial $VO_2$max test. After the tabata workout, the subject will complete a 3-minute cool-down on the cycle ergometer, which then is followed by 30-minutes of a randomized recovery modality (passive, active, or NormaTec). A blood sample for measuring blood lactate will be taken from the subject before the warm-up, after the cool-down, and then every 5-minutes during the recovery period. Following the recovery period's the subjects will be asked to complete two different recovery questionnaires.

The subject will also be required to complete a series of 3 different tests within 24-48 hours of each Tabata workout. The series of three tests will consist of three trials of a maximal vertical jump, three trials of a lateral quickness test (T-Test), and a 30-second maximal effort test on the cycle ergometer. This series of 3 tests will also be completed prior to the start of this study to be used as baseline comparison measurements. The subjects will be asked to complete the two different recovery questionnaires both before and after completing the series of 3 tests following each Tabata workout.

In total, the subject will be completing one maximal exertion cycle test, one baseline series of performance tests, three Tabata workouts followed by 30-minutes of recovery, and three series of performance tests within 24-48 hours of each Tabata workout.

3. Subject Participation

Subjects are required to be highly fit (currently exercising at least five times per week for at least 30 minutes) and could not have had any lower extremity or back injuries within the last six months. Each subject is required to complete a PAR-Q to screen for cardiovascular and orthopedic contraindictations to exercise.

4. Potential Risks and Discomforts

There exists the possibility of certain changes occurring during high-intensity exercise. They include abnormal blood pressure, fainting, irregular, fast or slow heart rhythm, and in rare instances, heart attack, stroke, or death.

5. Potential Benefits

Maximal testing information can be useful and subjects can utilize ventilatory threshold in their own training. Subjects will be exercising

6. Confidentiality

Subjects data will be anonymous. No names or other identifying information will be used when discussing or reporting data.

7. Voluntary Participation and Authorization Participants

Participation and authorization of information in this study is voluntary. The subject is able to withdraw from the study at any point for any reason.

**I authorize the use of my records, any observations, and findings found during the course of this study for education, publication and/or presentation.**

**I voluntarily agree to participate in this research study**

□ **Yes**

□ **No**

**I understand that I will be given a copy of this signed Consent Form.**

Name of Participant (print):

______________________________________________

Signature: Date:

______________________________________________

Name of Witness (print):

______________________________________________

Signature: Date:

______________________________________________

Person Obtaining Consent:

______________________________________________

Signature: Date:

______________________________________________

APPENDIX B

PHYSICAL ACTIVITY READINESS QUESTIONNAIRE

# 2019 PAR-Q+

## The Physical Activity Readiness Questionnaire for Everyone

The health benefits of regular physical activity are clear; more people should engage in physical activity every day of the week. Participating in physical activity is very safe for MOST people. This questionnaire will tell you whether it is necessary for you to seek further advice from your doctor OR a qualified exercise professional before becoming more physically active.

## GENERAL HEALTH QUESTIONS

| Please read the 7 questions below carefully and answer each one honestly: check YES or NO. | YES | NO |
|---|---|---|
| 1) Has your doctor ever said that you have a heart condition ☐ OR high blood pressure ☐? | ☐ | ☐ |
| 2) Do you feel pain in your chest at rest, during your daily activities of living, **OR** when you do physical activity? | ☐ | ☐ |
| 3) Do you lose balance because of dizziness **OR** have you lost consciousness in the last 12 months? Please answer **NO** if your dizziness was associated with over-breathing (including during vigorous exercise). | ☐ | ☐ |
| 4) Have you ever been diagnosed with another chronic medical condition (other than heart disease or high blood pressure)? **PLEASE LIST CONDITION(S) HERE:** ____________ | ☐ | ☐ |
| 5) Are you currently taking prescribed medications for a chronic medical condition? **PLEASE LIST CONDITION(S) AND MEDICATIONS HERE:** ____________ | ☐ | ☐ |
| 6) Do you currently have (or have had within the past 12 months) a bone, joint, or soft tissue (muscle, ligament, or tendon) problem that could be made worse by becoming more physically active? Please answer **NO** if you had a problem in the past, but it **does not limit your current ability** to be physically active. **PLEASE LIST CONDITION(S) HERE:** ____________ | ☐ | ☐ |
| 7) Has your doctor ever said that you should only do medically supervised physical activity? | ☐ | ☐ |

**If you answered NO to all of the questions above, you are cleared for physical activity.**
**Please sign the PARTICIPANT DECLARATION. You do not need to complete Pages 2 and 3.**

- Start becoming much more physically active – start slowly and build up gradually.
- Follow International Physical Activity Guidelines for your age (www.who.int/dietphysicalactivity/en/).
- You may take part in a health and fitness appraisal.
- If you are over the age of 45 yr and NOT accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.
- If you have any further questions, contact a qualified exercise professional.

**PARTICIPANT DECLARATION**

If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that the community/fitness center may retain a copy of this form for its records. In these instances, it will maintain the confidentiality of the same, complying with applicable law.

NAME ____________________ DATE ____________

SIGNATURE ____________________ WITNESS ____________

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER ____________________

**If you answered YES to one or more of the questions above, COMPLETE PAGES 2 AND 3.**

**Delay becoming more active if:**

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ at **www.eparmedx.com** before becoming more physically active.
- Your health changes - answer the questions on Pages 2 and 3 of this document and/or talk to your doctor or a qualified exercise professional before continuing with any physical activity program.

# APPENDIX C

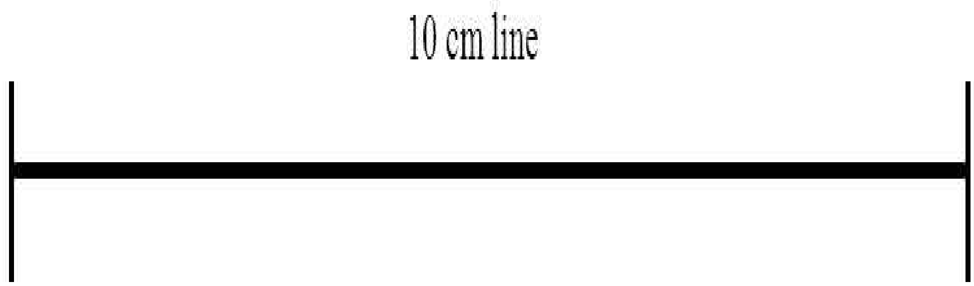
# TOTAL QUALITY RECOVERY SCALE

| Ratings of perceived exertion (RPE) | Total quality recovery (TQR) |
| --- | --- |
| 6 | 6 |
| 7 Very, very light | 7 Very, very poor recovery |
| 8 | 8 |
| 9 Very light | 9 Very poor recovery |
| 10 | 10 |
| 11 Fairly light | 11 Poor recovery |
| 12 | 12 |
| 13 Somewhat hard | 13 Reasonable recovery |
| 14 | 14 |
| 15 Hard | 15 Good recovery |
| 16 | 16 |
| 17 Very hard | 17 Very good recovery |
| 18 | 18 |
| 19 Very, very hard | 19 Very, very good recovery |
| 20 | 20 |

APPENDIX D

10-CM VISUAL ANALOG SCALE

# Visual Analog Scale (VAS)




Not at all recovered                                        Fully recovered

APPENDIX E

REVIEW OF LITERATURE

## Review of Related Literature

### Introduction

Athletes spend more time recovering from their respective training program's than actually completing them. This statement is true for all athletes regardless of the sport they participate in or how intense the training regimen. An athlete's recovery period is where most of their exercise-induced adaptations take place. Recovery can be broken down into three distinct subcategories according to Bishop, Jones, and Woods (2008). The smallest time period of recovery being between each consecutive repetition within the athlete's set. The second category is short-term recovery between repeats, which could be the time between resistance sets or interval bouts. Then, the third period is training recovery between consecutive workouts. The focus of the company Normatec, which manufactures and distributes a sequential PULSE pneumatic waveform, is primarily on the recovery period between successive training sessions (NormaTec, 2019).

One of the main claims that Normatec states that their sequential PULSE pneumatic waveform clears metabolites faster than passive recovery. Several researchers agree that an athlete's ability to speed up the recovery process may improve successive workouts, which could maximize the athlete's training quality or quantity, while also preventing injury or illness (Gill, 2006; Barnett, 2006). The appeal behind Normatec's recovery devices are that it mimics a cool-down, but claims to accelerate the recovery process by utilizing the body's normal physiological response and accelerating venous return.

## Intermittent Pneumatic Compression Devices

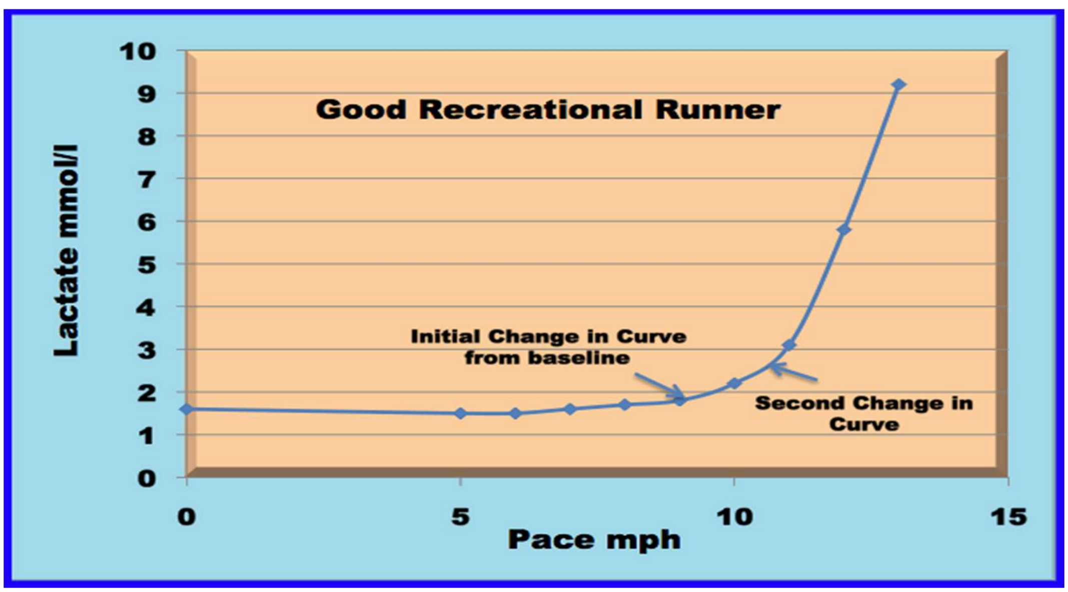
Intermittent pneumatic compression (IPC) devices, similar to Normatec's sequential PULSE pneumatic waveform, have recently gained popularity as a recovery modality. They started with clinical origins in the early 19$^{th}$ century as a means to improve circulation. More recently, clinicians have utilized IPC devices as a way to prevent post-surgery deep vein thrombosis. The pressure gradient created by the compression zone pushes the blood towards the heart and collapses the lumen of the vessel, which facilitates venous return (Khanna at al., 2008).

Sequential intermittent compression devices typically consist of inflatable garments that can be worn on the extremities; most often, as a boot that encloses the foot to upper thigh. A series of compartments in the boot inflate sequentially from distal to proximal and remain pressurized until three compartments, or zones, are inflated. Once three of the compartments are inflated, the device depressurizes the first zone so that only three zones have pressure at any given time (Northey et al., 2016). The IPC system, is intended to mimic the body's normal physiological venous return by applying pulsing compression, distal release, and gradients (NormaTec, 2019).

## Blood Lactate

Blood lactate accumulation (BLa) is a normal physiological response to exertion. The accumulation of metabolites, with BLa being one of them, has been shown to be one of the four basic processes associated with muscle fatigue (Zelikovski et al., 1993; Barnett, 2006). Normatec's claims to passively clear metabolites is designed to alleviate some elements of fatigue.

During incremental exercise the accumulation of BLa increases gradually and then increases exponentially above the lactate threshold. Lactate threshold typically ranges between 1.4 mM and 7.5 mM for different individuals (Goodwin et al., 2007). After "all-out" maximal exertion, BLa values can be as high as 15-25 mM. Values typically peak 3-5 minutes post-exercise and then decrease exponentially (Freund & Zouloumian, 1981). Historical data from Margaria, Edwards, and Dill (1933) showed that BLa decreases exponentially 6-8 minutes after the end of a high-intensity training session.




An Image of the Lactate Threshold off of Public Domain. Lactate.com. April 12, 2019. http://www.lactate.com/lactate_threshold_definitions.html

## Passive Recovery

Passive recovery is when an athlete completes their respective training and does not do any physical activity during the recovery time period. Passive recovery is the baseline for blood lactate clearance that is used in many studies. Determining whether a recovery strategy or modality is effective oftentimes uses passive recovery as the comparison condition. If the recovery modality is more effective than passive recovery, then it could be valuable, but if it is the same or less effective than passive recovery then it is not deemed to be useful for athletes.

With passive recovery, the half-life of muscle lactate is ~9.5 minutes and the half-life of blood lactate is ~15 minutes. This means that an individual's BLa concentration returns to resting levels within 90 minutes of a very high-intensity bout of exercise (Barnett, 2006). Greenwood, Moses, Bernadino, Gaesser, and Weltman (2008) found that passive recovery in swimmers completing a maximal 200-m swimming task, which the rate of blood lactate clearance was found to be 2.1 mM after 10 minutes.

## Active Recovery

The leading recovery technique for removal of BLa accumulation is active recovery (Monedero & Donne, 2006). Active recovery is the use of low-intensity exercise following heavy exercise, which has been suggested to increase muscle blood flow and allows for the re-oxygenation of blood through increased alveolar gas exchange (Crowther et al., 2007).

There has been no agreement amongst researchers as to the optimal intensity that active recovery should be performed (Zelikovski, 1993). A study conducted by Greenwood et al. (2008) evaluated different recovery strategies following a maximal 200-

meter swim. The researchers had their participants complete a 10-minute recovery either passively or actively at intensities related to their lactate thresholds.The researchers found that active recovery sessions at the participants lactate threshold intensity was the most efficient method of clearing blood lactate. This study concluded that active recovery at or near lactate threshold is not only the most efficient way to clear blood lactate ~8.5 mM over 10 minutes, but also improved subsequent performance when the swimmers were asked to complete another 200-meter maximal-effort swim.

**Intermittent Pneumatic Compression and Blood Lactate Clearance**

There have been several studies that have shown that IPC devices clear BLa more efficiently then passive recovery. Hanson, Stetter, Li, and Thomas (2013) studied 21 female student-athletes by having them complete a Wingate Test followed by a 20-minute recovery session. Subjects were randomly assigned to receive IPC recovery, active recovery, and passive recovery. They found that the IPC device was more effective then passive recovery at clearing BLa after anaerobic exercise. The 20-minute session with the IPC device was equally as effective at clearing BLa concentration as active recovery. A study done by Martin, Friedenreich, Borges, and Roberts (2015) compared IPC devices and passive recovery's effectiveness for removing BLa accumulation was. Subjects completed two, 30-second Wingate anaerobic tests separated by 3-minutes rest, followed by 30-minutes of treatment with either an IPC device or a sham. After the 30-minute recovery period, subjects were then asked to perform another 30-second Wingate test. Blood lactate concentration was evaluated at baseline and at regular intervals during recovery (5-, 15-, 25-, and 35-minute intervals post-fatigue protocol). They found that BLa was significantly lower at 25- and 35-minutes of recovery, which meant that the use of IPC devices may be a viable recovery tool.

Conversely, several studies have not shown IPC devices to be an effective modality for recovery BLa. Keck, Cuddy, Hailes, Dumke, and Ruby (2015) had 10 active males perform two, 90-minute bike rides followed by four hours of recovery with either an IPC device or passive recovery. Blood lactate concentrations between the two groups did not differ, which indicated that the IPC was no more effective at clearing BLa then passive recovery. Overmayer and Driller (2018) also investigated the efficacy of IPC devices on exercise recovery. Trained cyclists performed a fixed-intensity, 20-minute cycling bout on a cycle ergometer, followed by a 30-minute recovery period. After the recovery period, participants completed a 4-minute maximal cycling bout. The researchers found that there was no significant difference between the use of the IPC device and passive recovery on the clearance of BLa during the recovery period. Marcello, Fortini, and Greer (2019) had 10 subjects perform two consecutive 60-minute rides at 60% of their functional power threshold, with a 30-minute rest between rides. The subjects were either assigned to IPC boots or sitting in a similar position without boots. The same trials were conducted 7 days later with the conditions completed in the reverse order. Marcello et al. (2019) concluded that IPC boots use between cycling trails increased the BLa during subsequent exercise.

There also have been studies on the use of IPC devices before bouts of exercise, which has been shown to have no effect on anaerobic performance or BLa during recovery. The researchers preconditioned their subjects with 30-minutes of treatment with an IPC device. The subjects then were asked to perform a Wingate Anaerobic Test. The results showed that there was no significant difference in blood lactate between groups who were pre-treated and groups who were not (Martin et al., 2015).

## Massage and Blood Lactate Clearance

Normatec's sequential PULSE pneumatic waveform technology (PULSE 2.0) may imitate the effects of massage on recovery due to the dynamic compression, or pulsing, acting on the extremities.  A meta-analyses done by Weerapong, Hume, and Kolt (2005) showed that the studies on massage and increases in blood flow have been largely inconclusive due to several limiting factors. The studies that have examined the relationship between massage and increased blood flow concluded that there was no change in total muscle blood flow with massage (Zelikovski et al., 1993). The tests used techniques such as the Xenon Wash-Out Technique and venous occlusion pethysmography, which both have been proven to have methodological weaknesses (Barnett, 2006). Hoffman, Badowski, Chin, and Stuempfle (2016) had participants complete a 161.3 kilometer trail run with extended inclines and declines. Within 45-minutes after the race, participants were randomly assigned to receive either 20-minutes of IPC therapy or massage. It was found that IPC therapy and massage both gave immediate subjective benefits to participants, but did not provide any extended or functional benefits in the 7 days following the race. Monedero and Donne (2000) tested 18 male cyclists who performed two, 5-km maximal effort cycling bouts, followed by 20 minutes of recovery. The researchers randomly assigned participants to passive recovery, active recovery, and massage groups. The researchers found that active recovery was the most efficient intervention for the removal of BLa.

## Intermittent Pneumatic Compression as a Recovery Modality

Intermittent pneumatic compression devices are a relatively recent recovery modality used amongst athletes to accelerate their recovery. Athletes are in a never ending quest to find the most effective method of recovery, which can help shift their stress-recovery balance away from the stresses incurred from rigorous training (Barnett, 2006). Many of the recovery modalities commonly used amongst athletes lack research evidence to support their effectiveness. Normatec's sequential PULSE pneumatic waveform devices claims to be able to utilize "biomimicry", which is supposed to greatly enhance the movement of fluids and metabolites out of the limbs following intense training sessions (NormaTec, 2019). However, these claims are not conclusively supported by research evidence. There is a need for more conclusive research comparing Normatec's claims to accelerate the body's ability to clear metabolites, such as blood lactate.

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