THE EFFECT OF KINESIOLOGY TAPE APPLICATION DURATION ON ENDURANCE OF KNEE DURING AN ISOTONIC FATIGUING FLEXION/EXTENSION EXERCISE

by

En-Yi Wu

A Thesis Submitted in

Partial Fulfillment of the

Requirements for the Degree of

Master of Science

in Engineering

at

The University of Wisconsin-Milwaukee

August 2020

ABSTRACT

THE EFFECT OF KINESIOLOGY TAPE APPLICATION DURATION ON ENDURANCE OF KNEE DURING AN ISOTONIC FATIGUING FLEXION/EXTENSION EXERCISE

by

En-Yi Wu

The University of Wisconsin-Milwaukee, 2020
Under the Supervision of Professor Naira Campbell-Kyureghyan

Kinesiology Tape (KT) is an elastic athletic tape and is popular among athletes as it was claimed that it can to be worn for several days and is capable of preventing injuries, improving rehabilitation processes, improving muscle oxygenation levels, and enhancing muscle performance. The goal of this study was to determine if there was any potential enhancing effect of KT on joint endurance in healthy subjects, in particular with respect to time to fatigue (TTF), muscle oxygenation, and muscle activity in fatiguing knee flexion/extension exercise across sessions.

Fourteen healthy male subjects with no previous history of knee injury participated in this study. The study consisted of 8 sessions at 24-hour increments over 8 consecutive days. The first session, session 0, was set as a practice session and was excluded from analysis. Data collection started from session 1 and continued through session 7. Session 1 was set as the baseline session without KT. KT was placed on one knee (treatment knee) on session 2 and was kept in place for four sessions across 72 hours. The study observed the effect of immediate application and application durations up to 72 hours. KT was removed after session 5 (72 hours) to determine if there is any residual effect for the last

2 sessions (6 and 7). The other knee was kept as a control knee without KT to observe any potential learning effect across the 7 sessions.

Throughout the trials, TTF, number of cycles, cycle rate, bilateral muscle activity, and muscle oxygenation were recorded. To investigate the effect of application, each parameter was compared between pre-application (session 1) and application (session 2) in the treatment knee using paired-t test. A general linear model ANOVA was performed to determine the statistical significance of changes in the parameters across sessions for the treatment and control knees. The factor of subject was blocked in the analysis.

Results showed that there was no change in TTF or number of cycles from pre-application (session 1) to application session (session 2) in the treatment knee. No observed improvement in muscle oxygenation or muscle activity in either VL or VM was observed due to KT application.

During the application sessions there was a gradual increase in TTF and number of cycles in the treatment knee. There was also an observed delay in fatigue based on the evaluation of muscle oxygenation and muscle activity. Nevertheless, there were also gradual increases in TTF and number of cycles in the control knee. Control knee also had delay in the fatigue of muscle activity. The percent changes in the treatment and control knees were similar, which indicated that the learning effect was the reason for the growth of muscle endurance. Video records and seat pressure data, which were examined in another study, both showed postural changes of the subjects and a learning effect across sessions.

One finding of this study was that muscle oxygenation and muscle activity suggested muscle synergy during fatiguing knee flexion/extension, which was not discussed in previous studies of KT application. Another finding was the gradual increase in muscle endurance, in terms of TTF and number of cycles, in the control knee for 14 subjects across sessions, which revealing the significant effect from learning and postural change. This study suggests that future studies should take muscle synergy and learning effect into consideration when evaluating the effect of KT application or other types of medical application on joint performance and endurance.

© Copyright by En-Yi Wu, 2020
All Rights Reserved

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

I would like to acknowledge my advisor, Dr. Naira Campbell-Kyureghyan for contributing a great amount of time to work with me on this project and always providing opportunities for me to practice presenting the research to others. I would like to thank my two other committee members, Dr. Wilkistar Otieno and Dr. Yu David, for the assistance and support they provided me throughout this process. A special thanks is extended to Dr. Blake Johnson, Madiha Ahmed, Sam Wang, and Patrick Dix for data collection and processing.

Chapter 1 Introduction

1.1 Background

Kinesio tape (KT) is a brand of elastic sports tape was originally developed by a Japanese chiropractor, Dr. Kenso Kase in the 1970s (Williams et al., 2012). Kinesio tape became popular after it was donated to international sport teams from more than 50 countries during the Beijing Olympic games in 2008 (Jessop, 2014; Parker-Pope, 2008). The brightly colored tapes over athletes' skin have been successfully noticed by audiences.

According to manufacturer claims, KT has been worn continuously by individuals for three to four days without allergy (Huang, et al., 2017). Kinesio tape also has numerous functions claimed as shown in Table 1:

Table 1. Functions Claimed for KT Application

No.	Functions	Reference
1	Injury prevention	(Halseth, 2004; KT Health LLC, 2011; Implus LLC, 2019)
2	Rehabilitation process improvement	(Jaraczewska & Long, 2006; Kinesio LLC, 2019; Implus LLC, 2019)
3	Fatigue prevention	(KT Health LLC, 2010; Barten, 2020)
4	Performance enhancement (Muscular strength and functions)	(Aktas & Baltaci, 2011; KT Health LLC, 2010; Barten, 2020)
5	Quicker recovery of Carpal tunnel	(KT Health LLC, 2019; RocktapeAustralia, 2013)
6	Quicker relief from runner's knee, wrist, shoulder, and back pain	(KT Health LLC, 2019; Agocs, 2017)

However, a controversy still remains in scientific literature regarding the evidence of any efficacy of KT. Though the manufacturers have delivered numerous scientific papers that support their claimed benefits, several recent systematic reviews and meta-analyses have shown that there is limited or no evidence of a positive effect of KT, and that more studies are needed for clarification (Ramírez-Vélez, et al., 2019; Luz Júnior et al., 2019; Morris et al., 2013). A systematic review and meta-analysis which focused on the effect of KT on decreasing muscle pain revealed that 55.7% of relevant KT research papers (227 out of 407) published before 2012 were not randomized controlled trials. The quality of the experimental design was limited and needed to be improved upon. Therefore, continued examination on the efficacy of the taping with a higher quality of experimental design and further elucidations are required (Morris et al., 2013).

Occupational therapists often recommend that patients purchase KT based on anecdotal studies, and several existing research papers have shown some effects of KT application on muscle pain and relief. (Kalichman et al., 2018; Öztürk et al., 2016; González-Iglesias, 2009). However, the use of KT still does not have sufficient scientific research-based evidence to justify its use.

The study by González-Iglesias (2009) examined effects of immediate and post 24-hour KT application on neck pain and range of motion (ROM) in forty-one patients (21 female patients and 20 male patients) who have acute whiplash injury. Subjects received KT or sham tape application randomly. Subjects and the assessor both were blinded to intervention allocation. The outcomes were shown to be statistically significant with a one-point decrease in pain measurement (1-11 scale) and a five-degree increase in ROM on patients in treatment group after immediate KT application and 24 hours application compared to the baseline values. However, as the author of this study pointed out, a one-point measured pain decrease and five-degree increase in ROM both are below the standard of clinical significance.

Another subsequent systematic review focused on clinical effects of KT on shoulder, low back and neck pain compared to the results of sham tape. After screening out low-quality research, the remaining six high-quality randomized controlled trials studies presented only low to medium quality of evidence to support the effect of KT on musculoskeletal conditions (Morris et al., 2013). This study suggested that more high-quality randomized controlled trials are required to increase the evidence of KT efficacy.

Following the systematic reviews in 2013, Luz Junior (2019) published another systematic review on the effectiveness of KT in patients with chronic nonspecific low back pain. This study showed that the effect of KT application for low back pain relief is minimal and not clinically significant as the previous studies had presented. The change in pain intensity and disability after KT application were compared to no intervention, placebo, exercise, and exercise combined with KT. Some patients felt their pain decreased with the KT application, however the results of this systematic review with meta-analysis showed that the overall effect of KT application is not clinically significant on decreasing non-specific low back pain intensity and disability. The researcher opposes the use of taping since the results do not demonstrate that KT is better than placebo tape for patients with non-specific low back pain.

Additionally, researchers carried out several studies on the immediate application of KT on jumping, cycling, and muscle strength based on the manufacturer's claim that KT application can enhance muscle performance (Lins et al., 2016; Vercelli et al., 2012; Yam, 2019; Oliveira, 2016; Trecroci, 2017). The literature reviews showed no immediate effect of KT application on performance enhancement. Some research presented a positive enhancing effect of KT application, but randomization was not thoroughly considered, and the results were inconsistent (Müller, 2015; Reneker, 2018).

Japanese researchers published a systemic review and meta-analysis that was limited due to language barriers. They investigated papers related to the effect of immediate KT application for lower limb muscles on isokinetic knee extension strength, vertical jumping, running, and balance. The results showed limited evidence to support the use of KT application for performance enhancement. The reason for the limited evidence of support is insufficient details of interventions reported and the lack of high-quality studies on KT (Mine et al., 2018).

Hébert-Losier (2019) applied KT on knee patella and observed muscle activity of vastus lateralis (VL), vastus medialis (VM), rectus femoris (RF), bicep femoris (BF), and kinematic movement during cycling compared to the activities without KT. Electromyography signals were collected from VL, VM, RF, and BF of twelve male cyclists after applying KT across their patella on both knees during 4-minute sub-maximal cycling exercises. The results showed minimal effects of KT on all kinematic measures, but KT improved normalized mean and peak EMG and integrated EMG of vastus medialis.

Choi and Lee (2018) tested the effect of KT application on quadriceps strength of fifteen healthy subjects (10 male and 5 female) during isokinetic knee flexion and extension exercise. The results showed that KT application was able to increase the peak torque of the quadriceps. However, the researchers failed to randomize the sequence of intervention as well as not presenting the statistical power, and all values of the standard deviation were high. In addition, the researchers did not standardize the torque by subjects' mass which varied over a wide range.

Serra et al. (2015), investigated KT application effect on maximal isometric knee extensor testing using the change in maximum knee extension force, time to maximum force, and the onset power in the beginning 200-ms force time on thirty-four soccer players (20 male and 14 female) after immediate or post 24-hour KT application. The subjects' quadriceps and knees were applied KT or micropore tape (placebo) randomly. The results showed no enhancing effect on time to maximum force, force performance, or the onset power based on the results for the confidence interval and effect size.

In 2018, Reneker et al. wrote a systematic review on the effect of immediate and post 24-hour KT application on healthy male and female subjects. The focus was on how KT application affects functional sports performance, e.g., jumping, cycling, sprint speed, and long-distance running, etc. The results of fifteen medium and high quality of papers showed the indifference between the performances with tape, placebo tape, and without tape situations (Reneker et al., 2018).

Vercelli (2012) carried out a within-subject study to observe the enhancing effect on jumping and the peak torque from immediate KT application for the quadriceps muscles. Repeated isokinetic maximum torque tests, as well as single leg hop distance tests, were performed by thirty-four healthy male and female subjects. Each subject went through three sessions with different types of taping: KT application on the quadriceps muscles and below the knee, KT on the Vastus Lateralis, Vastus Medialis and below the knee, and sham taping were used in each session randomly. The results showed no difference on single leg hop distance and peak torque between types of tapings and no immediate enhancing effect from KT application.

Poon (2014) studied the effect of the immediate application of KT on the knee with no injury history during isokinetic knee extension. The results displayed no effect on total work, peak torque, and time to peak torque from KT application and indicated that the improvement might come from placebo effect.

The reviewed studies frequently indicated that there was no immediate effect of KT on sport performance enhancement and strength of knee extension and flexion. However, the effect of longer duration of KT application on healthy subjects is unclear. Only a small number of researches have investigated performance enhancement beyond post 24 hours of KT application. Furthermore, few studies discussed the effect of KT on muscle endurance or delay in time to fatigue.

Muscular endurance is defined as the capacity of a muscle or muscle group to sustain repeated high-intensity low-resistance activity for a prolonged period of time (Hickson, 1988). The force-time integral was calculated and used as a measure of muscle endurance by Fisher (1991). The number of repetitions performed was noted as a measure of endurance by Wernbom (2006). Kinesio tape has been claimed to enhance muscle endurance by delaying muscle fatigue (Choi & Lee, 2019; Abubaker et al., 2018; Álvarez-Álvareza, 2014).

Strength recovery of fatigued quadriceps was investigated after applying KT on the Vastus Lateralis, Rectus Femoris, and Vastus Medialis (Choi & Lee, 2019; Choi & Lee, 2018). The results suggest that the application of KT in any direction can improve the strength of fatigued muscles during sport activities. However, the intervention sequences were not randomized which allowed for a potential learning effect.

Furthermore, out of the studies reported positive results after KT application the majority were not within-subject studies (Trecroci, 2017; Abubaker, 2018; Álvarez-

Álvareza, 2014). Improvement in muscle endurance was also observed in subjects who wore sham tape, indicating the placebo effect (Stedge et al., 2012; Lee, 2017).

In contrast, only a few studies of effect of KT application have looked at the changes in regional muscle oxygenation saturation (rSO_2) levels after the KT application (Pliner, 2015; Wang. 2018). Since muscle oxygenation is one of the indicators of muscle fatigue (Boushel, 2000), the observation on the change in muscle oxygenation can assist in determining if KT can delay muscle fatigue. Moreover, muscle activity (EMG) can also be an indicator to muscle fatigue (Thongpanja et al., 2013).

Based on the literature review, isometric (constant muscle length) exercise and isokinetic (constant speed) exercise are the methods most often chosen to test the effectiveness of KT application. Isometric exercise is very frequently used in post-injury or post-surgical rehabilitation (Fisher et al. 1991). Most studies on KT effectiveness application utilized isokinetic exercise since it is viewed as a beneficial technique to help injured athletes rehabilitate faster and with more success (Osternig, 1986). Few studies have tested the application of KT during an isotonic (constant force) exercise. Guilhem et al. (2011) have shown isotonic testing can reveal higher electromyography activity of agonist muscles than isokinetic testing.

Researchers have tended to study the effect of immediate application of KT on subject performance. However, these studies at best have been insufficient concerning the long-term effect from KT application on the knee joint. More importantly, short-term and long-term are not well defined. Based on the reports of the inventor, Dr. Kase (2011) claimed that after a 10-min application the blood flow and circulation are improved. Generally, short-term or immediate application has been defined as 24 hours or less, and long-term application is beyond 24 hours. However, users usually apply KT for prolonged days since the tape can be used for three to four days without removal. Many researchers also noted that the long-term effect of KT are unknown and need to be studied. The intention of this study on isotonic exercise should help to complete the gap in knowledge.

1.2 Goal of The Study and Hypothesis

This study investigates the effect of KT application duration (dose-response effect) on three knee extensor muscle - Vastus Lateralis (VL), Vastus Madialis (VM) and Rectus Femoris (RF) - endurance during fatiguing isotonic knee flexion/extension exercise. More specifically, the study aims to quantify endurance changes due to prolonged KT application through measuring the changes in time to fatigue, the number of cycles, muscle activity, and regional muscle oxygenation level with duration of exposure. It was hypothesized that KT application will enhance the performance, and an increase in duration of KT application will result in delay of fatigue and consequently in a delay of muscle oxygenation drop and decreased change in muscle activity. The detailed of hypotheses are in the below:

H1. KT application can enhance knee joints endurance during isotonic fatiguing knee flexion/extension exercise.

H1a: Application of KT will delay TTF during knee isotonic flexion/extension fatiguing exercise.

H1b: Application of KT will result in increase of number of cycles during knee isotonic flexion/extension fatiguing exercise.

H1c: Application of KT will result in delay of time to minimum muscle rSO_2 during knee isotonic flexion/extension fatiguing exercise.

H1d: Application of KT will reduce the drop of muscle rSO_2 rate during knee isotonic flexion/extension fatiguing exercise.

H1e: Application of KT will delay muscle fatigue during knee isotonic flexion/extension fatiguing exercise

H2. KT application durations can enhance knee joints endurance during isotonic fatiguing knee flexion/extension exercise.

H2a: Application durations of KT will delay TTF during knee isotonic flexion/extension fatiguing exercise.

H2b: Application durations of KT will result in increase of number of cycles during knee isotonic flexion/extension fatiguing exercise.

H2c: Application durations of KT will result in delay of time to minimum muscle rSO_2 during knee isotonic flexion/extension fatiguing exercise.

H2d: Application durations of KT will reduce the drop of muscle rSO_2 rate during knee isotonic flexion/extension fatiguing exercise.

H2e: Application durations of KT will delay muscle fatigue during knee isotonic flexion/extension fatiguing exercise.

H3. Learning effect can enhance knee joints endurance during isotonic fatiguing knee flexion/extension exercise.

H3a: Learning effect will delay TTF during knee isotonic flexion/extension fatiguing exercise.

H3b: Learning effect will result in increase of number of cycles during knee isotonic flexion/extension fatiguing exercise.

H3c: Learning effect will result in delay of time to minimum muscle rSO_2 during knee isotonic flexion/extension fatiguing exercise.

H3d: Learning effect will reduce the drop of muscle rSO_2 rate during knee isotonic flexion/extension fatiguing exercise.

H3e: Learning effect will delay muscle fatigue during knee isotonic flexion/extension fatiguing exercise.

Chapter 2 Methods

2.1 Subjects

2.1.1 Pilot Study

A pilot study exploring the effect of Kinesio tape (KT) on knee flexion/extension performance and biomechanical improvement was conducted to determine the required sample size and refine the experimental protocol. Statistical power analysis was performed using G*Power 3.1 (Faul et al., 2009). A minimum of 11 subjects were found to be required for a statistical power of 80% based on the result of the power analysis (Table 2).

*Table 2. Results of G*Power analysis*

Statistical Power	Required sample size
0.95	17
0.90	14
0.85	13
0.80	11
0.75	10

2.1.2 IRB Approval

The study experimental design, procedures, and informed consent form were reviewed and approved by the University of Wisconsin-Milwaukee Institutional Review Board (#15.372) prior to subject recruitment. All test sessions were conducted by experienced and trained team members of Spine Biomechanics Laboratory. Subjects were recruited using flyers and by word of mouth. The participants received a custom designed UWM T-shirt as a token of appreciation.

2.1.3 Screening

Prior to testing, all subjects were interviewed about any history of previous or current knee injuries or pain. Inclusion criteria were healthy males who were 18 years or older, with no previous injuries or current knee pain, and a regular weekly exercise routine. Exclusion criteria for subjects were individuals with a history of knee injury or knee pain within the 6 months prior to day 1 of their scheduled testing dates.

2.1.4 Subject Information

After recruitment, fourteen male volunteers (age, 22 ± 1.5 years; height, 72.2 ± 2.0 inches; and weight, 168.7 ± 22.5 pounds) with no knee injury or pain for the past 6 months were recruited and participated in this study across eight consecutive days each. Written informed consent was obtained from each subject prior to testing.

2.2 Experimental Design

2.2.1 Independent Variable

The duration of KT application, as an independent variable, was varied in 24-hour increments for 4 days. There were two pre-KT application sessions, one of which (session 0) was a practice session, and another one (session 1) was used as a baseline session for later comparison use. Four post-KT application sessions and two post-KT removal sessions followed the two pre-KT application sessions. Figure 1 provides a block design diagram of the experimental design.

2.2.2 Dependent Variables

The primary dependent variable of Time to Fatigue (TTF) and the Number of Cycles were utilized as indicators of knee joint endurance. TTF is defined as the duration from beginning to end of the trial when the subject can no longer perform the exercise.

Secondary dependent variables of interest that were collected include: Regional Muscle Oxygenation Saturation level (rSO_2) of Vastus Lateralis (VL) and Vastus Medialis (VM) and electromyography (EMG) of the VL, VM and Rectus Femoris (RF).

2.3 Experimental Protocol

All subjects attended 8 sessions at 24-hour increments (± 2 hours) over 8 consecutive days (Figure 1). They were asked to perform two fatiguing unilateral isotonic knee extension/flexion exercises in each session, one test each for the left and right knee joints. The subject's dominant leg was set as the experimental treatment knee for observing the effect of KT on the endurance of the knee. Subjects were asked which leg they kick a ball with, and this indicated which leg was dominant. The non-dominant leg was identified as the control knee which had no KT applied throughout the entirety of the study to observe and account for any "learning effect" which could confound the results. The sequence of which knee would be tested first was randomized for all sessions.

In session 0 no KT was used (nKT*) and this session was used to familiarize the subjects with the testing protocol and thus is excluded from analysis. In session 1 occurred 24 hours after session 0 and there was also no KT application (nKT_0). This session was used to measure the pre-treatment performance without any KT application. Twenty-four hours after session 1, KT was applied to the subject's dominant knee during session 2 (KT_0) as the immediate application (0 hours) trial. The same researcher applied KT on all subject's knees throughout the study.

KT was applied at the beginning of Session 2

KT was removed at the end of Session 5

14 Subjects	Session 0	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7
Treatment Knee	Practice	Baseline	KT	KT	KT	KT	No KT	No KT
Control Knee	Practice	Baseline	No KT	No KT	No KT	No KT	No KT	No KT

Figure 1. A block diagram of experimental design

KT was applied using the guidelines specified by the manufacturer. In this experiment, one 5-inch-long (12.7-cm-long) and two 10-inch-long (25.4-cm-long) strips of KT were used on the experimental treatment knee. The researcher instructed the subject to bend their treatment knee to 90 degrees of flexion and to maintain the posture while KT tapes were being placed on the skin. The shortest strip was fully stretched and then applied under the subject's kneecap. One long strip was anchored on the quad and moderately stretched across the bottom of the kneecap, and then the end of the strip was placed with no stretch. The third strip was applied in a manner similar to the second strip. The two long tapes made as an "X" as shown in Figure 2. KT was left on the treatment leg and was not removed until session 5.

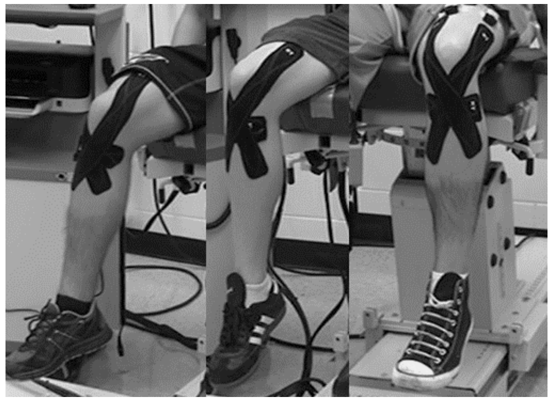


Figure 2. Tape placement on three different subjects

The overall experimental protocol used for all the test sessions is detailed in the following section. The sequence of steps during each testing session is presented and is also illustrated in Figure 3.

1. A semi-structured interview was conducted for subject preparation. Subjects were asked to document their normal daily activities, or their activities since the last test session, and the number of hours they slept the night before each test session to check if there were any changes in their status.
2. Kinesio was applied to the subject's dominant knee (the experimental treatment knee) before the test during session 2. KT was removed after session 5.
3. EMG and rSO_2 sensors were attached to the VL, VM, and RF before each session.
4. Subjects were asked to sit on a Biodex dynamometer System 4 and their shoulder, back, pelvis, and thigh positions were fixed to the seatback and seat using harness straps. Each strap was tightened but was not uncomfortable for each subject. Movements of the upper body, waist, and thigh were limited in order to eliminate confounding effects from compensation by other muscles. The Biodex knee attachment was bound to the subject's shin to allow for the addition of a 40-pound

(18 kg) resistance load. The isotonic fatiguing protocol started after the sensors, KT, and Biodex placements were ready.

5. Subjects were asked to perform the knee flexion/extension exercise (Figure 4) until they could no longer perform.
6. After each test, subjects were given a 10-minute rest before the second knee test was performed using the same protocol.
7. Finally, subjects answered a questionnaire and all sensors were removed.

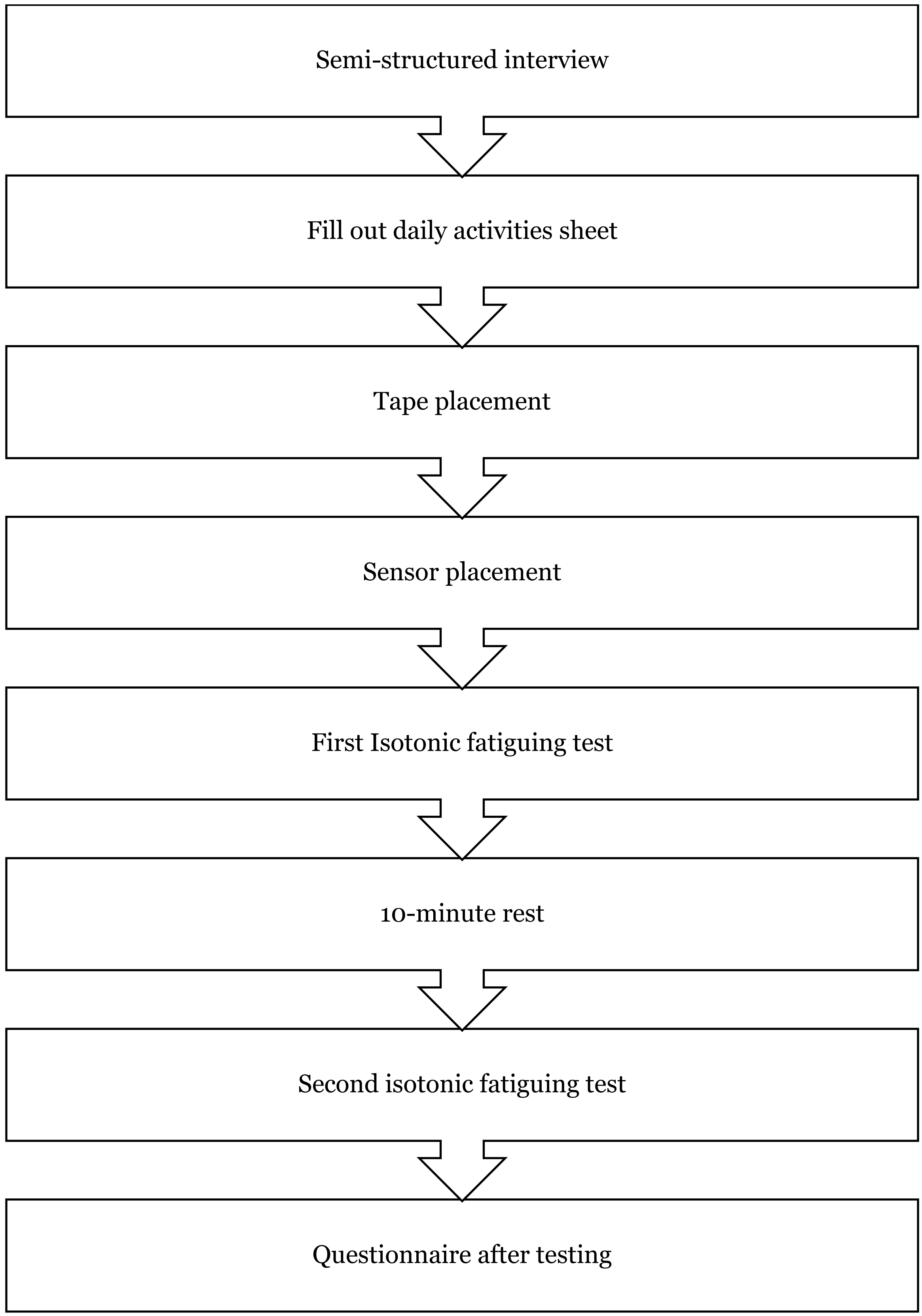


Figure 3. Order of events during testing sessions

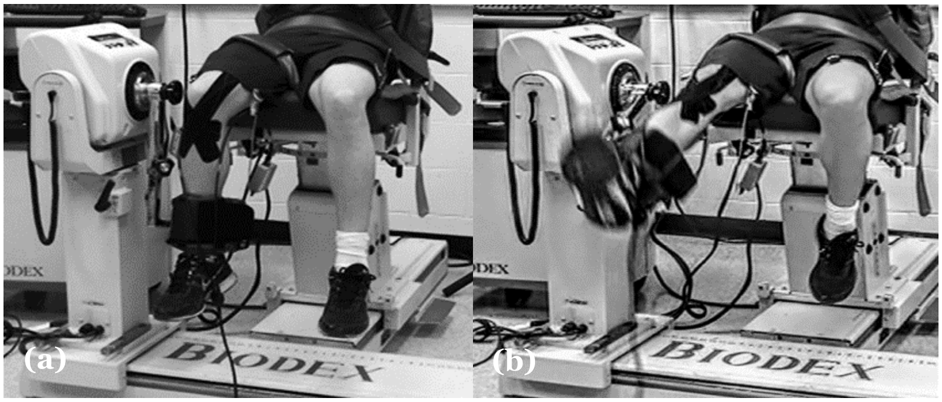


Figure 4. Knee in (a) the flexed and (b) extended position during the test

2.4 Equipment, Data Collection and Processing

2.4.1 Dynamometer

The Biodex dynamometer System 4 (Biodex Medical Systems, Shirley, NY, USA) was used to standardize the knee joint flexion/extension throughout the testing as seen in Figure 4. Machine based testing is recommended as it provides a higher level of standardization on kinematic tests compared to free functional movements and manual resistance tests (Konrad, 2006). The knee attachment was set up on the subject's shin to allow for adding a fixed amount of resistance to the testing protocol (Figure 5). The knee adapter was coupled to the knee and only allowed subjects to have forward knee extension and backward flexion during the tests.

Figure 5. Subject placed in Biodex for testing

2.4.1.1 Time to fatigue (TTF)

Knee joint endurance or Time to Fatigue (TTF) data collection and measures were completed using the Biodex System and was exported as text files and converted to excel files for processing. Time to fatigue data was also recorded on paper, and the electronic data was checked against the manual records for consistency. The percent change in TTF (ΔTTF) was processed and calculated as follows:

$$\Delta\text{TTF}(\%) = \frac{\text{TTF}_{ij} - TTF_{nKT0_j}}{TTF_{nKT0_j}} \times 100\%$$

i = 0, 24, 48, 72, nKT_1, nKT_2 *and* j = 1…,14

Where i is the duration of application in hours and j is the subject number.

2.4.1.2Number of cycles

Performance for this study was also represented as the number of cycles counted from the start of the trial until the time when the subject could no longer perform the exercise. An increase in the number of cycles would be representative of an enhancement in performance. The change in the number for each trial was calculated.

2.4.2 Regional Muscle Oxygenation Saturation (rSO_2)

Regional Muscle Oxygen Saturation (rSO_2) levels is a physiological evidence that could help explain potential changes observed in TTF. Near-infrared spectroscopy allows the researchers to assess the oxidation–reduction state (Boushel & Piantadosi, 2000). When subjects exercise, their muscles consume oxygen to generate energy consistently, and the oxygenation saturation in muscles reduces during exercise (Smith K.J., 2010). Muscles have been deemed to be fatigued when the muscles were out of oxygen (Murthy, Hargens, Lehman, & Rempel, 2006). Subjects in this study were observed to be fatigued during exercise while their oxygenation saturation dropped. At the same time, when mechanoreceptors sensed the relatively great accumulation of carbon dioxide, they will convey neural signals to the brain. The brainstem will modulate respiratory drive to increase the breathing rate and volume. (Brinkman, Toro, & Sharma, 2018). The heart rate would also increase to deliver oxygen demanded toward the exercising muscles for prolonging the performance (Joyner & Casey, 2015). In contrast, the limited oxygen supply in the muscles causes muscle fatigue (Cifrek, Medved, Tonkovića, & Ostojića, 2009). One study showed that KT increase skin blood flow (Craighead, Shank, & Volz, 2017). The improvement in oxygen delivery can slow down muscle fatigue (Hepple R. , 2002). As a result, KT application is assumed to delay the time to fatigue and the time to minimum oxygenation levels. Namely, to slow down the drop rate of oxygenation to reach the minimum levels at a later time. Therefore, if the tape could delay muscle fatigue, it should be able to lengthen the performance in terms of TTF and number of cycles. In terms of oxygenation, the time to minimum rSO_2 level should be able to be delayed, and the drop rate of oxygenation should be slowed down.

rSO_2 levels were collected using Nonin Medical's Equanox, Model 7600 NIRS as seen in Figure 6 (Nonin Medical Inc., Plymouth, MN, USA). The oximeter uses near-infrared spectroscopy (NIRS) to measure changes in muscle oxygen non-invasively (Boushel et al., 2001). Before placing a NIRS sensor, the surface of the skin was cleaned with alcohol. A hypoallergenic tape was applied to secure the sensor in place and to prevent any movement during the test.

Figure 6. Near-infrared spectroscopy system

The change in rSO_2 levels was collected using the eVsion 1.2.0 system (Nonin Medical Inc., Plymouth, MN, USA) at a frequency of 0.25 Hz (maximum frequency allowed by the device). Data was exported as several excel files for further processing.

The baseline rSO_2 level was defined as the value at the beginning of each trial before the fatiguing protocol. Calculation of the baseline rSO_2 level was the average of the last 16 seconds of rSO_2 values prior to the test. The baseline rSO_2 level was used for later normalization of rSO_2.

The first observed oxygenation parameter is the time to minimum rSO_2 (TTM) as seen in Figure 7. This measure indicates the onset of muscle fatigue. Time to minimum rSO_2 is defined as the time from the start of the trial until the time the rSO_2 saturation of subjects dropped to the lowest level. Time to minimum rSO_2 was normalized as a percent of the overall trial time as follows:

$$\text{Normalized TTM}_{ijk}(\%) = \frac{\text{TTM}_{ijk}}{\text{TTF}_{ij}} \times 100\%$$

$i = 0, 24, 48, 72, \text{nKT}_1, \text{nKT}_2$ and $j = 1\ldots,14$ and $k = \text{VL, VM}$

where i is the duration of application in hours, j is the subject number, and k is the observed muscle. Change in TTM was observed by performing separate pairwise comparisons between session 1 and sessions 2, 3, 4, 5, 6 and 7.

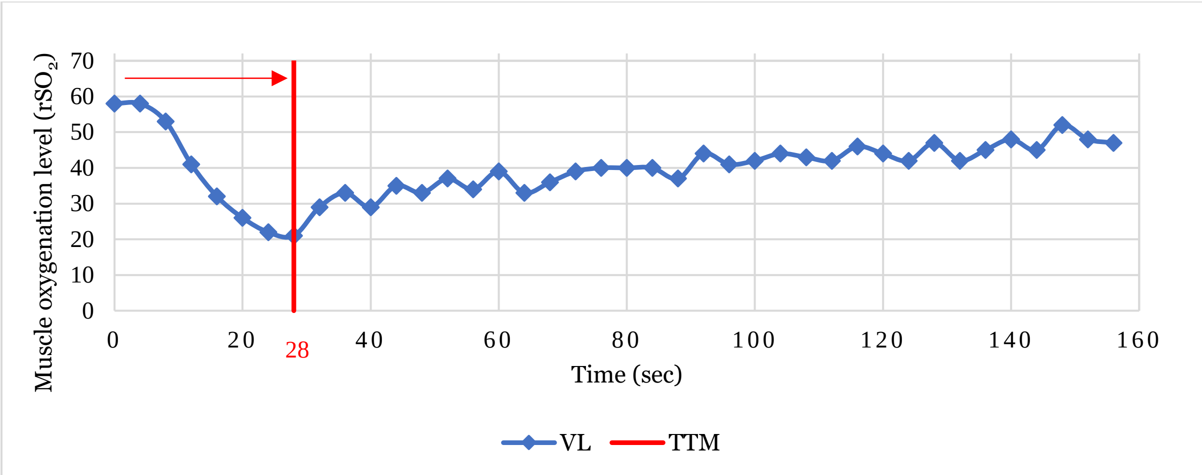


Figure 7. Muscle oxygenation status change of a subject's VL during a test session. Muscle oxygenation saturation level was tracked from the start of the test until the time the subject exercised to exhaustion. Time to minimum oxygenation was marked when the lowest rSO2 was identified. In this example, the TTM was identified at the 28th second.

Rate_rSO_2 is defined as the rate of muscle oxygenation drop to the minimum level. The Rate_rSO_2 was monitored to see if KT application and the application duration help decrease the rate. A decreased rSO_2 rate should be observed if KT enhances oxygen delivery. The effect of duration is observed by performing separate pairwise comparisons of Δrate_rSO_2 between session 1 and sessions 2, 3, 4, 5, 6 and 7.

2.4.3 Electromyography (EMG)

Muscle activity signals were recorded using double differential wireless EMG surface electrodes. Signal form each electrode was transmitted and recorded to data logger and laptop as shown in Figure 8 (Delsys Inc, Boston, MA, USA). The EMG signals of VL, VM, and RF were recorded on both the dominant and non-dominant legs of subjects. The EMG measurements allow for voluntary neuromuscular status observation and analysis (Konrad, 2006). The placement areas were shaved and cleaned with rubbing alcohol to decrease the risk of data collection artifacts each day before the exercise. After skin preparation, sensors were applied parallel to each muscle fiber direction on a muscle belly. All sensors were secured with a hypo-allergenic tape to prevent the sensors from falling off or losing contact with the subject's skin during the test.

Figure 8. Delsys EMG system sensors

Data collection of electromyography (EMG) signals were monitored using EMGworks 4.0 Acquisition software (Delsys Inc., Boston, MA, USA) and sampled at 2,000 Hz. Data processing was carried out using the software EMGworks 4.1.7 Analysis (Delsys Inc, Boston, MA, USA). The EMG signals were filtered using a fourth-order, bandpass Butterworth filter with 20 - 450 Hz frequency (Passband Ripple: 3.0 dB, Attenuation: 40.0 dB) (De Luca et al., 2010). Then, the RMG signals were divided into window lengths set at 100ms based on a literature review of similar studies. A shorter window allows higher sensitivity to identify the change of signal during dynamic exercise (Konrad, 2006; Ulrey & Fathallah, 2013; Rutherford et al., 2011; Picchiotti et al., 2019; Hudson et al., 2016; Ramsook et al., 2017). Although signals were divided into 100ms-long windows, the windows were overlapped by 50% (50ms) to identify amplitude (Scott, 2014; da Silva et al., 2015).

The amplitude of the EMG signal was processed as the root mean square (RMS). When subjects fatigued, RMS values increase over time because muscles increase their recruitment of motor units (Figure 9). The increase in RMS is used as another fatigue index. The RMS was calculated using an assigned moving window length within each window of data calculated according to the following equation:

$$\text{RMS} = \sqrt{\frac{1}{T_2 - T_1}\int_{T_1}^{T_2} [f\ (t)]^2\ dx}$$

where T_1 and T_2 are the current window time points range and $[f\ (t)]^2$ is the signal data within the window.

The moving RMS window algorithm quantifies signals, makes negative values into positive, and calculates RMS amplitudes of the signal (Gupta et al., 2017). Large differences in amplitude of muscle signals has been observed between different muscles, days, and even individuals. As a result, this variation requires the normalization of the RMS in order to obtain a higher internal validity of comparison of EMG data. The normalized RMS is calculated as a ratio of the maximal RMS value in each session as:

$$\text{Normalized RMS}_{ijk} = \frac{RMS_{ijk}}{Maximal\ RMS_{ijk}}$$

$i = 0, 24, 48, 72, \text{nKT}_1, \text{nKT}_2$ and $j = 1\ldots,14$ and $k = \text{VL, VM, RF}$

Where i is the duration of application, j is the subject number, and k is the observed muscle.

The average RMS in each session was calculated for the further comparison. The change in average RMS across sessions was compared to see the effect of application durations on the treatment knee and the learning effect on the control knee. Considering the variety of TTF subjects performed, average rate of change in RMS in each session was also calculated.

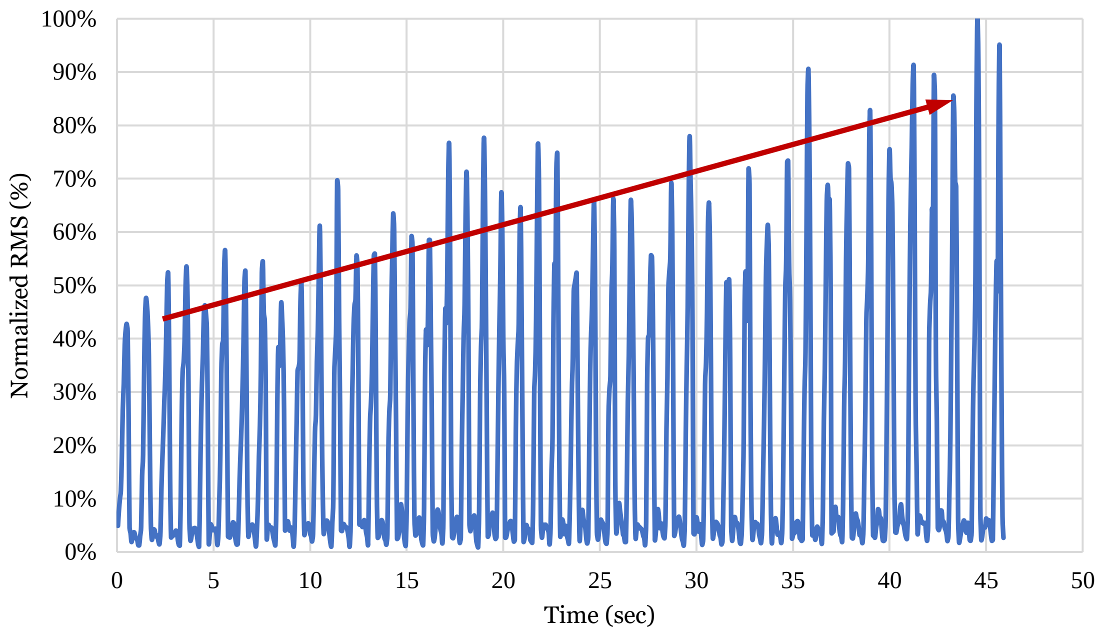


Figure 9. The change in RMS of a subject's VL during a test session.

The average rate of change in normalized RMS of VL, VM and RF in each session was calculated as:

$$Average\ rate\ of\ change\ in\ RMS = \frac{\sum_{a=o}^{n}\left(\frac{RMS_{a_{ijk}}}{Maximal\ RMS_{ijk}}\right)}{n \times TTF_{ij}} \times 100$$

i = 0, 24, 48, 72, nKT_1, nKT_2 and j = 1…,14 and k = VL, VM, RF where a is the number of data points, i is the duration of application, j is the subject number, and k is the observed muscle.

Median frequency (MDF) of the EMG signal were calculated since MDF is another indicator of muscle fatigue. When subjects feel fatigued, MDF values will decrease over time. The change in the rate of change in MDF across sessions was calculated to determine if KT application could delay muscle fatigue. MDF was averaged from the start to the end of a trial as the average MDF in each session. If average MDF becomes higher across application sessions, it means that the fatigue is delayed. The average MDF divided by TTF is defined as the average rate of change in MDF in each session:

$$Average\ rate\ of\ change\ in\ MDF = \frac{\sum_{a=o}^{n}\left(MDF_{a_{ijk}}\right)}{n \times TTF_{ij}}$$

i = 0, 24, 48, 72, nKT_1, nKT_2 and j = 1…,14 and k = VL, VM, RF

where a is the number of data points, i is the duration of application, j is the subject number, and k is the observed muscle.

2.5 Statistical Analysis

Statistical tests are separately performed for each hypothesis:

2.5.1 KT versus No-KT

This research aim is to determine the effect of KT application on the endurance of VL, VM, and RF of the treatment knee. As a result, for further statistical analysis, this research used the one-sided paired t-test to compare pre-application and KT application session as shown in Figure 10.

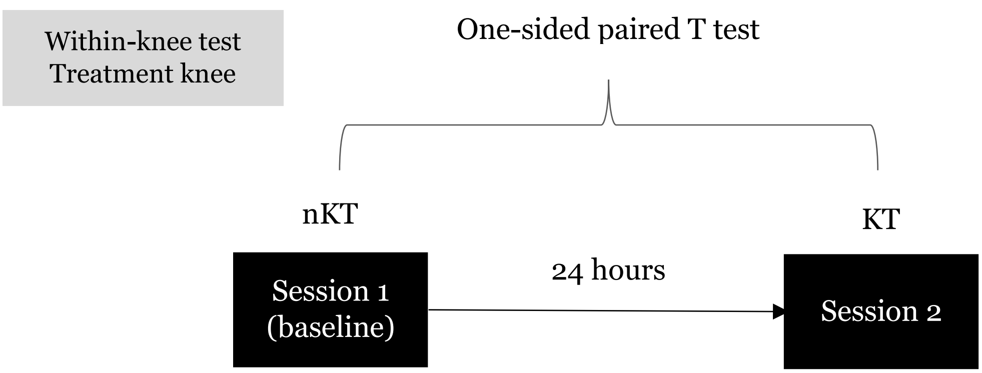


Figure 10: Comparison diagram I

2.5.2 Duration of the KT Application

This research aim is to determine the changes in endurance of VL, VM, and RF of the treatment knee over the various durations of KT application. A General Linear Model ANOVA was used to test the effect of the duration of KT application on the treatment knee within subjects as seen in Figure 11. Alpha level is set as 0.05.

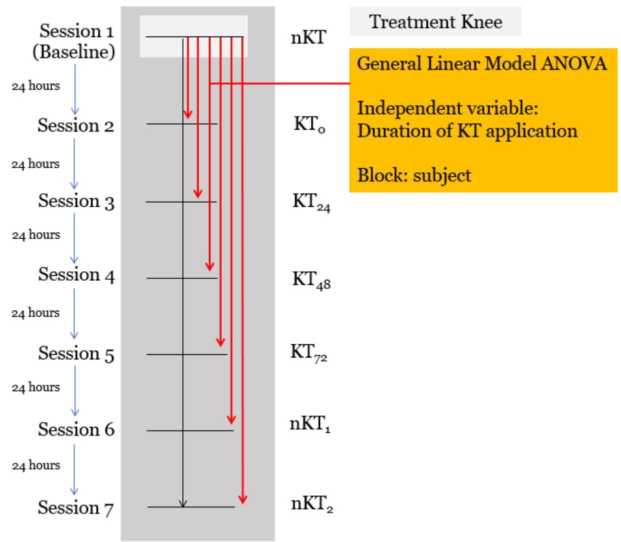


Figure 11: Comparison diagram II

2.5.3 Learning Effect

Another General Linear Model ANOVA was performed on the outcome measures from the control knee to observe the possible presence of a learning effect (Figure 12). All calculations were done in MINITAB (Version 19). Tukey Pairwise Comparisons were used as the post-doc method.

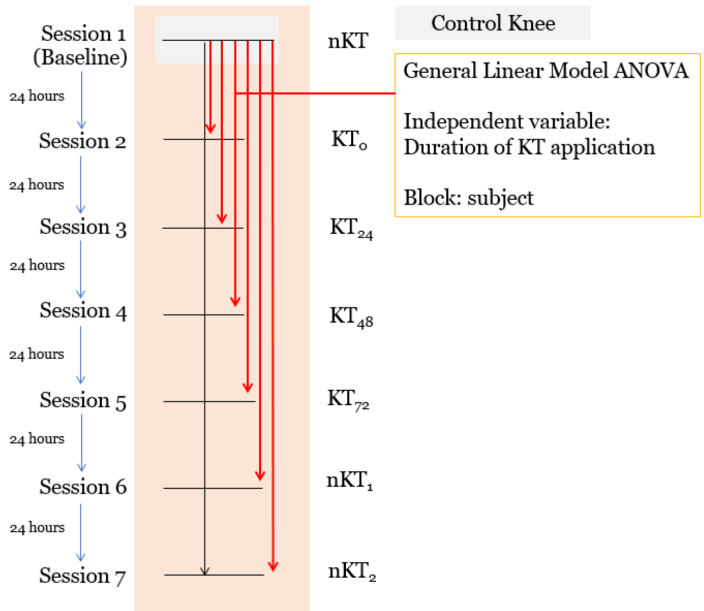


Figure 12: Comparison diagram III

Chapter 3 Results

The first section of the results will focus on the effect of KT application by performing the comparison between session 1 (no KT) and session 2 (KT) of knee flexion and extension. The second section will present the results of the effect of duration on the control knee (learning effect) and the treatment knee (effect of prolonged application) The effect of learning was observed in the control knee from session 1 to session 7, each 24-hours apart. The effect of KT application was observed in

3.1 The Effect of KT Application

3.1.1 Time to Fatigue

Time to fatigue is defined as the duration from beginning to end of the trial when the subject can no longer perform the exercise. The hypothesis is that the KT treatment application can enhance the endurance of muscles in terms of delay in TTF. One-sided paired t-test was carried out to test the hypothesis and the significance of the changes within each subject.

There was no significant difference in TTF between session 1 (baseline) and session 2 in the treatment knee (75.7 ± 72.1, 74.0 ± 68.6, $p = 0.779$). TTF for both session 1 and session 2 are shown in Figure 13. 8 out of 14 subjects 2, 3, 4, 5, 8, 9, 10, and 14 had slight increases in their TTF, while 6 of 14 subjects 1, 6, 7, 11, 12, and 13 had slight decreases from session 1 to 2 (Figure 13). The results also showed that the average change in TTF among the 14 subjects was an increase of 5.70 sec (±19.93 sec). Large changes in TTF (64 and 46 sec) were measured in subjects 3 and 4, which lead to a standard deviation value greater than the mean.

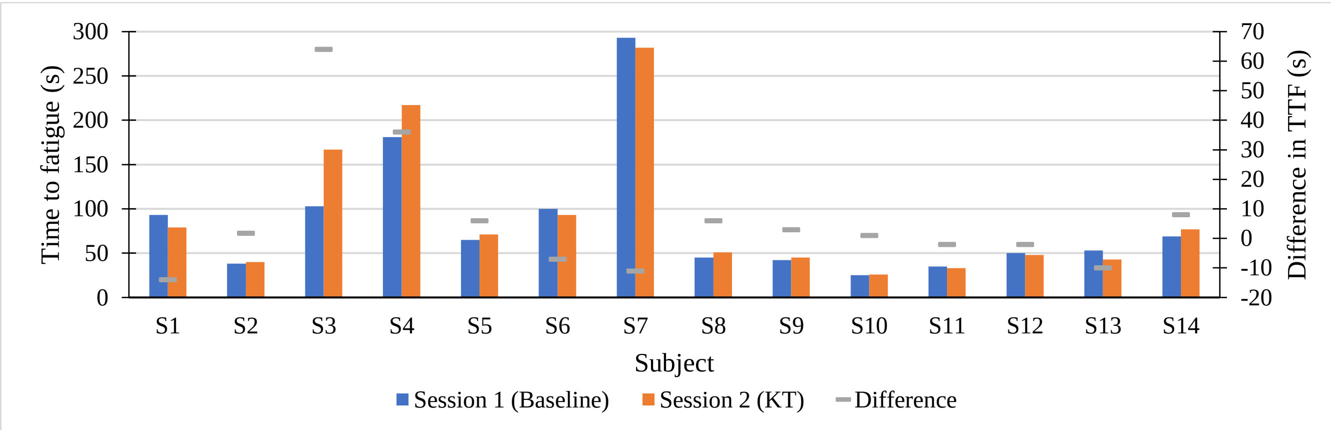


Figure 13. TTF of the treatment knee in session 1 (baseline) and session 2 (KT).

3.1.2 Number of Cycles

The hypothesis is that application of KT will result in increase of number of cycles during knee isotonic flexion/extension fatiguing exercise. A cycle is comprised of one full knee extension and a subsequent flexion back to 90 degrees. The number of cycles is defined as the number of knee extensions and flexions counted from the start of the trial until the time when the subject could no longer perform the exercise. For this measure performance was defined by the number of cycles.

It was found that the immediate application of KT did not substantially affect the number of cycles. The average increase in the number of cycles for the 14 subjects was 2.68 with a standard deviation of 18.61 (p = 0.346) for the treatment knee. From session 1 to session 2 the change in the number of cycles ranged from a decrease of 37 cycles to an increase of 57 cycles (Figure 14a). Subject 3 had a relatively high increase in the number of cycles, while subject 4 had a large decrease in the number of cycles, even though a large increase in TTF was observed for subject 4. Taken together, for subject 4 it appears that the large increase in TTF resulted in or from a slowing in the rate of extension/flexion exercises. Similarly, there was no substantial change in the number of cycles from session 1 to session 2 for the control knee with an average increase of 2.95 cycles (p = 0.164). Changes ranged from a 13-cycle decrease to a 17-cycle increase (Figure 14b).

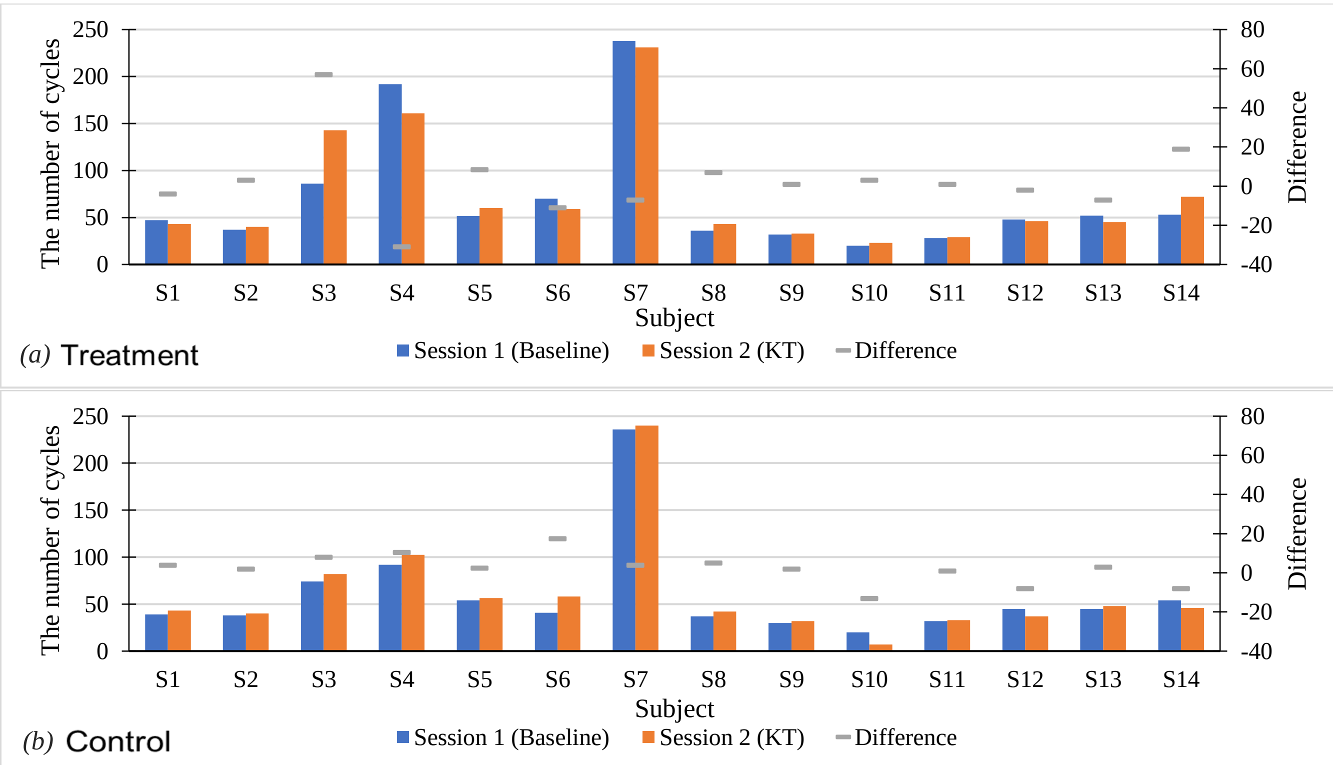


Figure 14. The numbers of cycles in session 1 (Baseline) and session 2 in (a) treatment knee and (b) control knee.

3.1.3 Muscle Oxygenation

The regional muscle oxygenation saturation level (rSO_2) began to decrease when the subject started to exercise. The time to minimum rSO_2 (TTM rSO_2) was defined as the time from the start of the trial until the time rSO_2 level dropped to the lowest level. The assumption was that TTF and TTM rSO_2 were directly proportional to each other. TTF was assumed to be delayed when TTM rSO_2 was delayed. Time to minimum rSO_2 could help physiologically explain any change in muscle endurance after KT application. Kinesio tape application was claimed to improve circulation for muscles, and as a result application of KT will result in delay of time to minimum muscle rSO2 during knee isotonic flexion/extension fatiguing exercise.

3.1.3.1 Time to minimum rSO_2 (TTM rSO_2)

Application of KT is hypothesized to result in delay of TTM rSO_2 during knee isotonic flexion/extension fatiguing exercise. TTM rSO_2 value in baseline session (session 1) was compared to session 2 (KT session) in each subject for understanding the effect of KT application. The results show that there is a great variety in TTM rSO_2 among subjects after KT application. The change in TTM rSO_2 in VL ranged between -62.79% and +15.46%, and the range of change in TTM rSO_2 in VM was between -7.92% and +28.31%. The average change in TTM rSO_2 for the treatment knee was a decrease of 7.22% (±22.40%) in VL and a decrease of 0.89% (±15.29%) in VM.

Based on the researcher's expectation, after KT was applied on both muscles, normalized TTM rSO_2 should have been increased in both muscles. However, as the result showed, the changes in TTM rSO_2 in VL (Figure 15a) and in VM (Figure 15b) were not correlated in the treatment knee. The uncorrelation was observed as TTM rSO_2 increased in VL, while a within-subject decrease in TTM rSO_2 in VM was observed. Likewise, while TTM rSO_2 in VM was decreasing, an increase in TTM rSO_2 in VL was noticed. This uncorrelated change in TTM rSO_2 was observed in 9 out of 14 subjects 3, 4, 5, 6, 8, 9, 10, 12, 13. This indicate that the coactivation of muscles and the support of muscle synergy. There were only 2 subjects 1 and 11 where an increase in TTM rSO_2 was observed for both muscles, and 3 subjects 2, 7, 14 had a decrease in both muscles. There was no significant increase in TTM rSO_2 observed in either muscle VL or VM after KT application ($p = 0.867$ and 0.546, respectively).

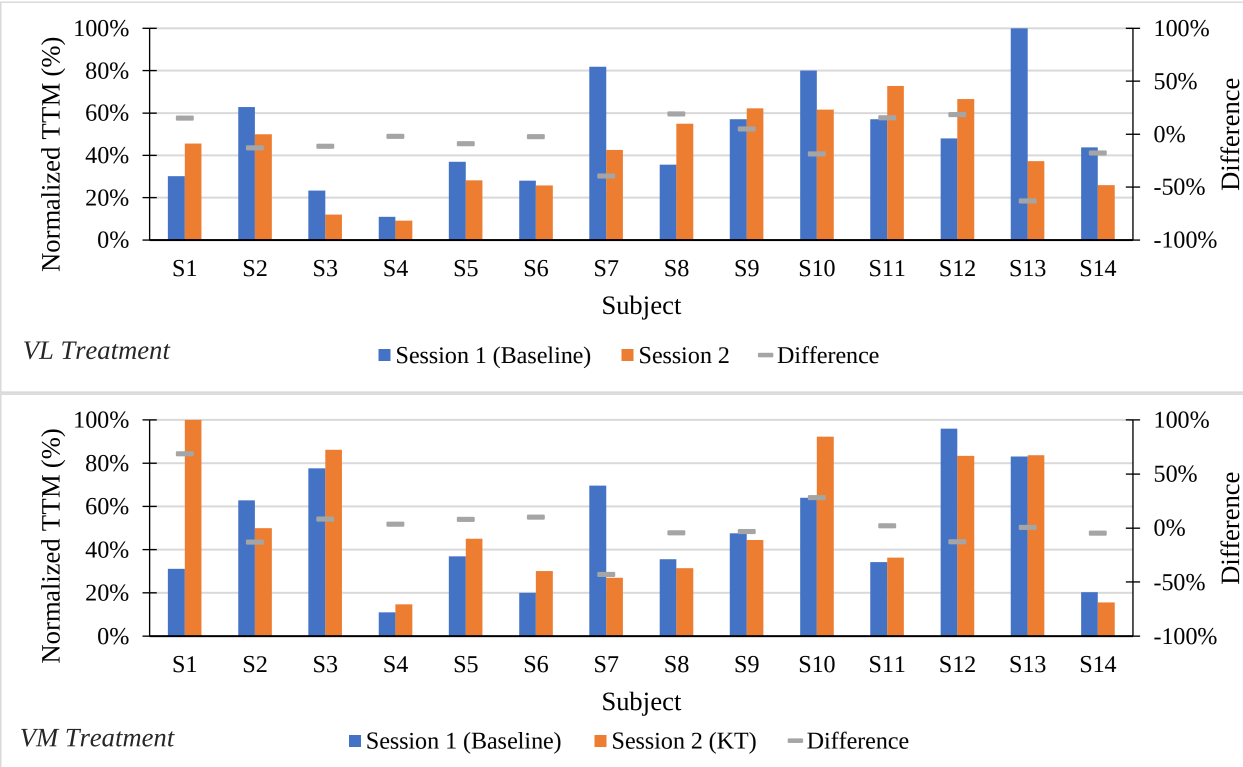


Figure 15. Normalized time to minimum oxygenation in the VL and VM of treatment knee in sessions 1 and 2. The disproportional change in VL and VM is observed.

3.1.3.2 Drop Rate of Regional Oxygenation Saturation (rate_rSO_2)

Drop rate of regional muscle oxygenation saturation is the rate of muscle oxygenation level drop from the baseline value to the value at the end of exercise. It is calculated and denoted as rate_rSO_2. The hypothesis is that Application of KT will reduce the drop of muscle rSO_2 rate during knee isotonic flexion/extension fatiguing exercise.

The result shows that 7 out of 14 subjects 3, 5, 7, 8, 9, 10, 11 experienced only minimal decreases in rate_rSO_2 of VL, while there were 7 subjects 1, 2, 4, 6, 12, 13, 14 experiencing an increase in rate_rSO_2 in the treatment knee (Figure 16). For the muscle VM, 7 subjects 2, 3, 4, 5, 7, 8, 9 had a decrease in rate_rSO_2, but 7 subjects had an increase in rate_rSO₂. According to the paired t-test, there was no significant reduction in rate_rSO₂ in the VL between session 1 (baseline) and session 2 (0.45 ± 0.3, 0.46.0 ± 0.3, respectively; p = 0.788) in the treatment knee. For rate_rSO₂ VM of treatment knee, there was also no significant reduction between sessions 1 and 2 (0.21 ± 0.14, 0.20.0 ± 0.16, respectively; p = 0.821). The results turned out that the average change in rate_rSO₂ increased by 0.01/sec (±0.14) in VL and decreased by 0.01/sec (±0.13) in VM among 14 subjects.

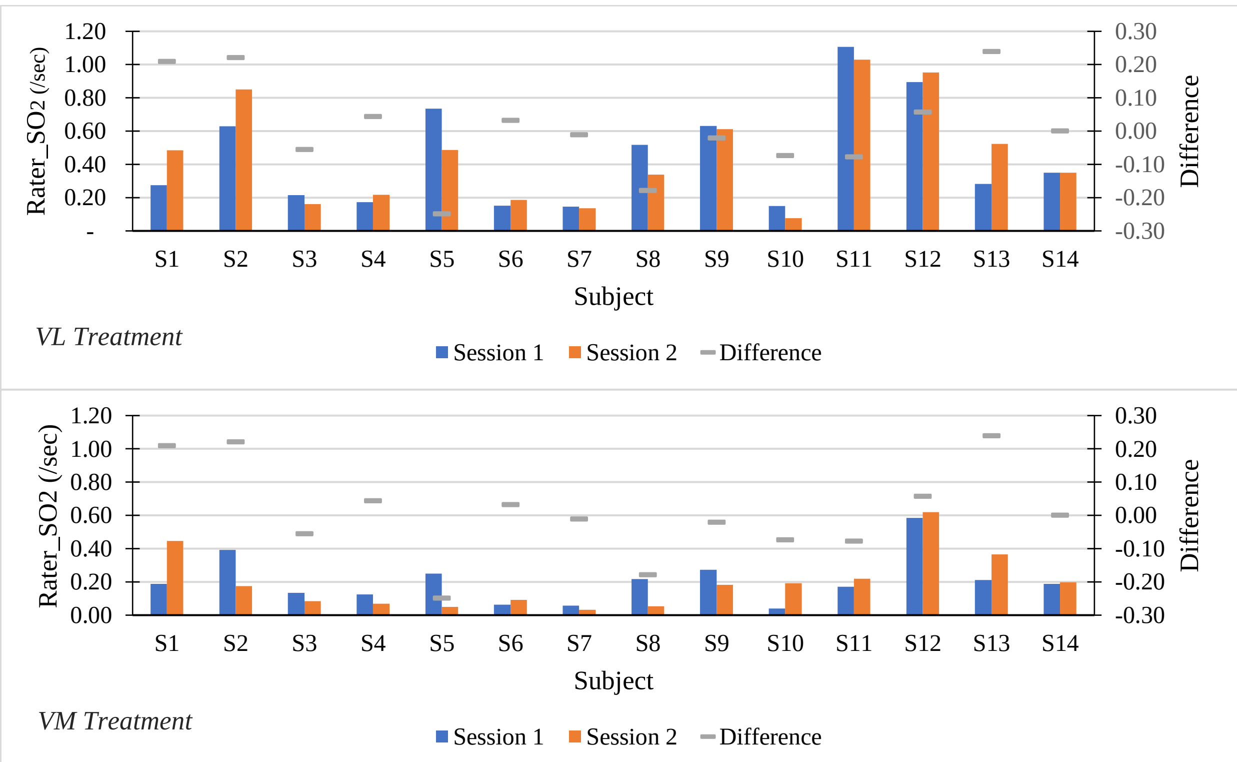


Figure 16. Changes in Rate rSO2 of VM between session 1 (Baseline) and session 2 (KT).

3.1.4 Muscle Activity

It was hypothesized that application of KT can result in a delay in muscle fatigue during isotonic knee flexion/extension exercise in terms of reduced changes in muscle activity.

3.1.4.1 Change in EMG RMS

The amplitude of the electromyography (EMG) signal was processed as the root mean squared (RMS), and the average RMS for each muscle was calculated in each session. The change in RMS as the rate of change per second was also calculated. A positive change in magnitude of RMS is considered to be a fatigue marker, as an increase in the RMS indicates the recruitment of additional muscle motor units. The hypothesis is that KT application can enhance the endurance of muscles in terms of a lower average RMS and a reduction in the rate of change in RMS after KT application.

Based on the results of one-sided paired t-test (Table 3), there was no substantial reduction in the average RMS in VL or RF in session 2 (KT) compared to session 1 (baseline) except VM. Average RMS in sessions 1 and 2 for each subject showed that 10 out of 14 subjects 1, 2, 3, 4, 5, 7, 9, 11, 12, 13 had a slightly decrease in average RMS for the VM muscle from session 1 to 2 (Figure 17b), but 8 of them (subjects 1, 2, 3, 4, 5, 7, 11, 13) had an increase in average RMS of either VL or RF, indicating muscle synergy and muscle coactivation. There were 7 subjects 1, 3, 5, 7, 11, 13, 14 that had no reduction in RMS of VL after KT application (Figure 17a). Seven subjects 2, 4, 5, 7, 8, 11, 13 had an increase in RMS of RF in session 2 (Figure 17c).

For the rate of change in RMS, there was substantial reduction in the rate of change in RMS was observed because of the large variation between subjects (Table 3). This suggested that immediate KT application did not delay the rate of muscle fatigue. This result was consistent with the change in TTF, number of cycles and drop rate change in muscle oxygenation.

Table 3. Normalized average RMS and rate of Change in RMS in treatment knee in sessions 1 and 2

Average RMS		Mean (SD)	*p*-value		Mean (SD)	*p*-value		Mean (SD)	*p*-value
Baseline average RMS	VL	0.22 (±0.05)	0.143	VM	0.23 (±0.04)	0.045	RF	0.20 (±0.06)	0.588
KT average RMS		0.21 (±0.04)			0.21 (±0.06)			0.20 (±0.06)	
Rate of change in RMS		Mean (SD)	*p*-value		Mean (SD)	*p*-value		Mean (SD)	*p*-value
Baseline rate of change in RMS (%/sec)	VL	0.42 (±0.36)	0.188	VM	0.44 (±0.34)	0.156	RF	0.38 (±0.37)	0.631
KT rate of change in RMS (%/sec)		0.39 (±0.31)			0.42 (±0.38)			0.41 (±0.37)	

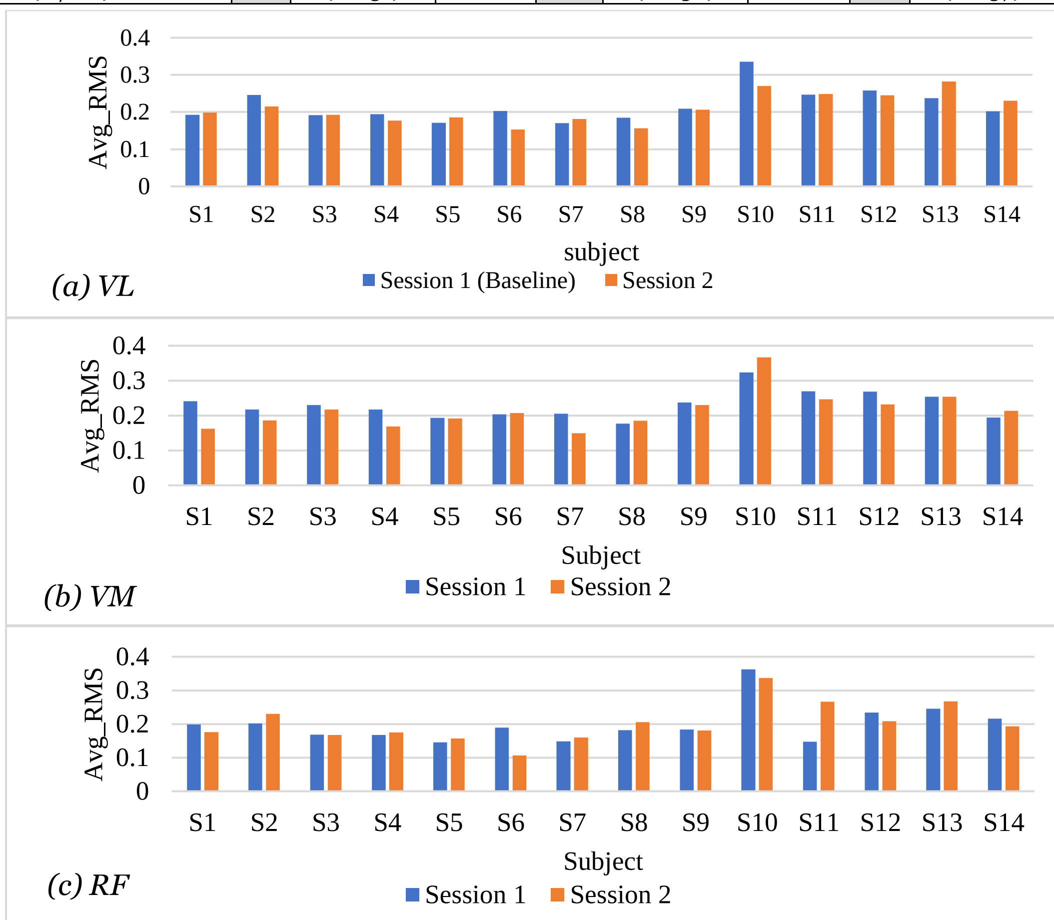


Figure 17. Comparison of percent change in RMS between session 1 and 2 in (a) VL (b) VM (c) RF.

3.1.4.2 Change in EMG MDF

The frequencies of the EMG signal were processed to determine the median frequency (MDF). The decrease in MDF is a commonly used fatigue index. When subjects are fatigued the value of MDF declines during exercise. The hypothesis is that the KT application will cause a larger average MDF and a reduction in the rate of change in MDF signifying a delay in muscle fatigue.

Based on the results of t-test (Table 4), there was no substantial reduction in the average MDF compared to baseline session. Average MDF for each subject in sessions 1 and 2 are shown in Figure 18. Average MDF for VL was slightly increased in 7 out of 14 subjects1, 2, 3, 4, 6, 7, 13, but the other 7 subjects had a decrease (Figure 18a). For VM, except for subjects 4, 6, 11, and 13, all other subjects had either no change or a decrease in average MDF (Figure 18b). For RF average MDF was slightly increased in 9 out of 14 subjects 1, 2, 3, 4, 6, 7, 11, 12, 13 (Figure 18c), although KT was not applied on RF.

The rate of change in MDF did not have a significant difference between sessions 1 and 2 because of the variation in results between subjects. On average, there was a decrease in the rate of change in MDF in all muscles (Table 4), however, it did not decrease for all subjects. While subjects 3 and 8 had a decrease in the rate of change in MDF of VL (-30% and -28%), subjects 1 and 13 had an increase of 42% and 40% in the rate of MDF change. Subjects 4, 5, 9, 10, 11 had a slight decrease in the rate, and subjects 6 and 7 had a moderate increase in the rate of change in MDF. Similar results were also observed in VM and RF in that 5 subjects still had a considerable increase in the rate of change in MDF (subjects 1, 6, 7, 11, 13).

Table 4. Normalized average MDF and the rate of change in MDF in sessions 1 and 2

Average MDF		Mean (SD)	p-value		Mean (SD)	p-value		Mean (SD)	p-value
Baseline average MDF	VL	57.98 (±6.92)	0.368	VM	57.88 (±7.10)	0.710	RF	57.32 (±8.04)	0175
KT average MDF		58.58 (±6.71)			57.35 (±6.10)			58.99 (±7.37)	
Rate of change in MDF		**Mean (SD)**	**p-value**		**Mean (SD)**	**p-value**		**Mean (SD)**	**p-value**
Baseline rate of change in MDF (/sec)	VL	1.06 (±0.61)	0.283	VM	1.06 (±0.64)	0.221	RF	1.06 (±0.68)	0.278
KT rate of change in MDF (/sec)		1.03 (±0.58)			1.01 (±0.54)			1.02 (±0.65)	

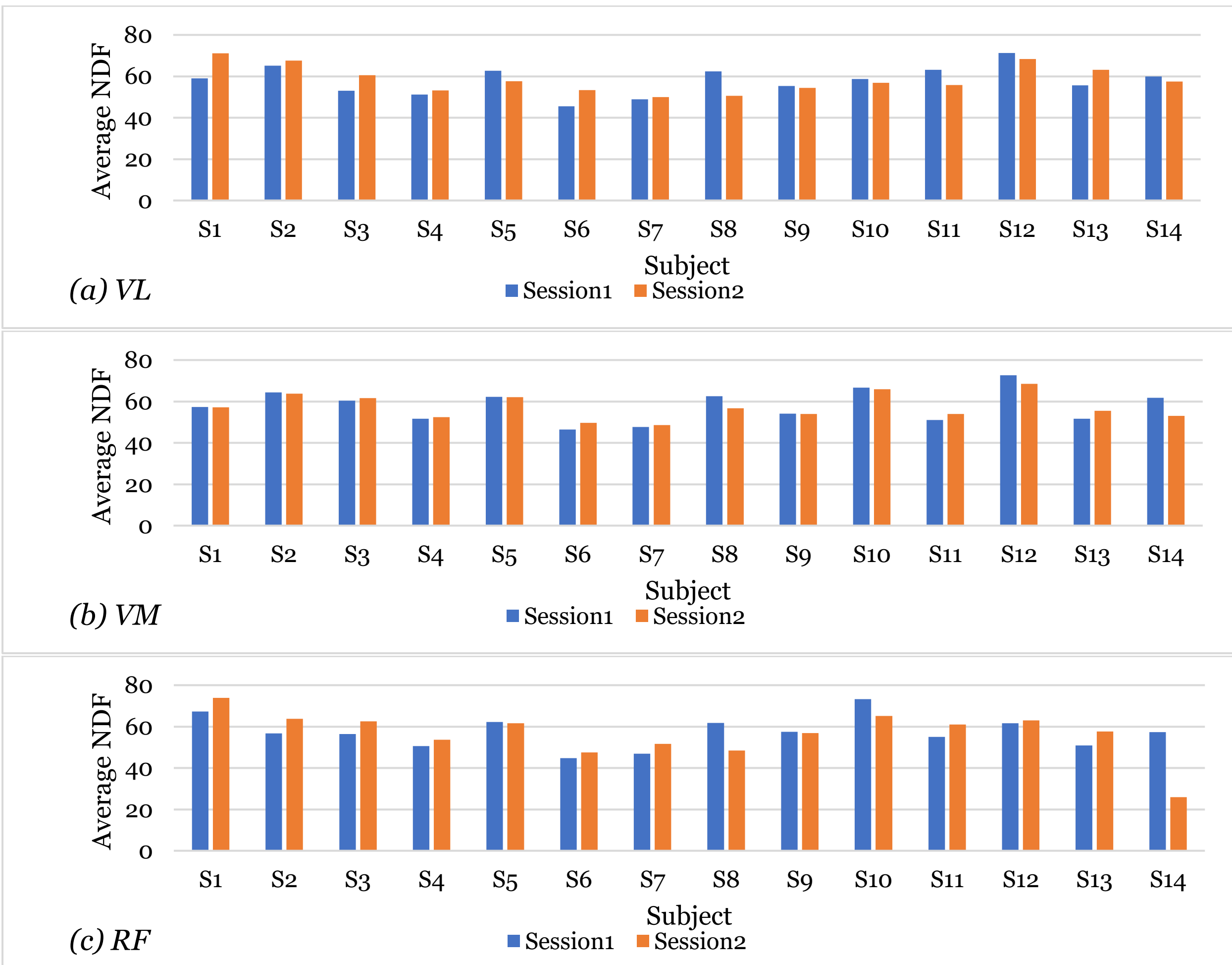


Figure 18. Average MDF of VL, VM, and RF in the treatment knee in sessions 1 and 2

3.1.5 Cycle Rates

Cycle rate is defined as a subject's average speed of knee flexion and extension during a test session. Cycle rate needs to be evaluated because a subject may try to extend their performance time by decelerating their speed, and therefore, that time increase may not be an indicator of enhancement of muscle endurance. The goal was to see if the change in cycle rate was significant and if it had any relation to the change in TTF.

A paired t-test was carried out to test the significance of the changes within each subject. According to the results, there was no significant difference in cycle rate between sessions 1 and 2 in the treatment knee (0.82 ± 0.13, 0.84 ± 0.13, p = 0.672). Nine out of fourteen subjects 1, 2, 3, 5, 8, 10, 11, 13, 14 had slight increases in cycle rate (Figure 19). Seven subjects had increases in TTF although they accelerated their cycle rate. Subject 14 had a larger increase in cycle rate in comparison to the other subjects but still had an increase of 8 seconds in TTF. A considerable decrease in cycle rate (0.32 repetition/sec) was found in subject 4 (Table 5), who had a dramatic increase in TTF by 46 seconds. Two subjects 6 and 9 had slight decreases in cycle rate from session 1 to 2, but an increase in TTF was only observed in subject 9. This may indicate that subjects decreased their cycle rate because of fatigue and did not make an actual improvement in TTF. Two subjects 7 and 12 had no change in cycle rate.

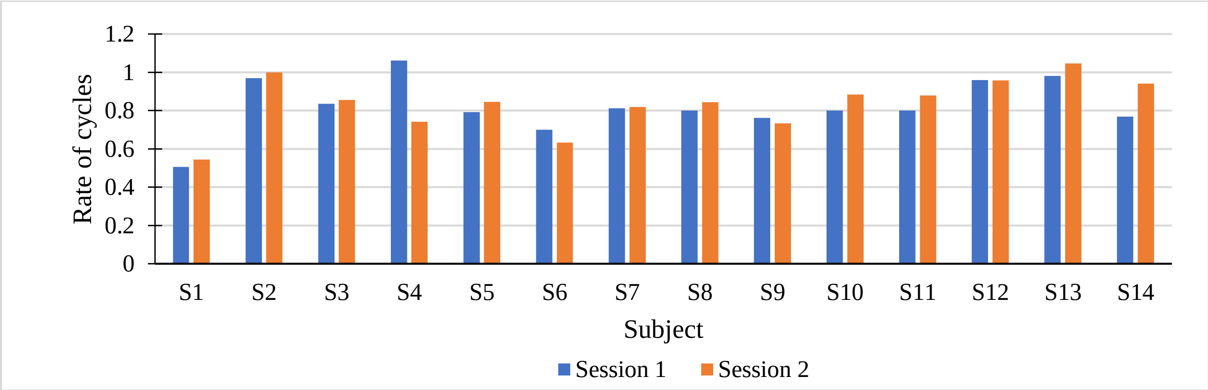


Figure 19. cycle rate of the treatment knee in session 1 and session 2.

Table 5. Results of change in cycle rate of 14 subjects between session 1 and 2

Rate of Cycle	Difference Values
Faster	S1,0.04; S2,0.03; S3, 0.02; S5, 0.05; S8, 0.04; S10, 0.08; S11, 0.08; S13, 0.05; S14, 0.17
Slower	S4, 0.32; S6, 0.07; S9, 0.03
No change	S7, 0.007; S12, 0.002

3.2 The Effect of Prolonged KT Application and Learning Effect

3.2.1 Time to Fatigue (TTF)

It was hypothesized that application durations of KT will delay TTF during knee isotonic flexion/extension fatiguing exercise. However, there was a large variation between subjects in TTF in the treatment knee across 4 sessions after KT application. TTF ranged between 17 and 441 seconds in the treatment knee. The KT application resulted in TTF changes ranging from a 62.00% decrease into an increase of 112% (Figure 20).

It was also hypothesized that learning effect will delay TTF during knee isotonic flexion/extension fatiguing exercise Change in TTF for the control knee. As the result showed, in the control knee, TTF ranged between 11 and 387 seconds. While the percent of change in TTF in the control knee ranged from a 59.57% decrease to an increase of 67.54% (Table 6). There was still a great variation between subjects.

The General Linear Model ANOVA shows that there was no significant difference with respect to the TTF for either the treatment or the control knees (p = 0.711 and 0.187, respectively) across durations, although the average percent changes in TTF were positive for both the treatment and control knee, indicating a delay in TTF (Table 6) as the sessions progressed.

Table 6. Results of percent change in TTF for each 24-hour increment of duration

	Treatment knee	Control knee

Duration(hrs)	Mean (SD) %	(Min, Max) %	*p*-value	Mean (SD) %	(Min, Max) %	*p*-value
0(Immediate)	5.55 (18.91)	(-18.87, 62.14)	0.711	2.94 (21.15)	(-52.17, 34.29)	0.187
24	6.77 (31.26)	(-62.00, 54.37)		7.67(22.99)	(-46.81, 53.97)	
48	11.79 (33.22)	(-60.00, 82.52)		19.37 (27.46)	(-59.57, 45.55)	
72	12.55 (40.76)	(-54.00, 111.65)		18.00 (32.87)	(-48.94, 67.54)	

Although application durations of KT was hypothesized to delay TTF, the effect of duration of KT application does not appear to have any clinical significance, but the learning effect is substantial. Except for four subjects 6, 10, 12, and 14 had experienced no increase in TTF for either knee, TTF was increased in 9 out of 14 subjects for both the treatment and control knees (subjects 1, 2, 4, 5, 7, 8, 9, 11 and 13) across sessions (Figures 20 and 21). It is postulated that the increases seen in both treatment and control knees are due to the learning effect, as time performances in the control and treatment knee increased over duration. There was subject 3 only that had a stable increase in TTF in the treatment knee but not in the control.

Since a learning effect was observed in both knees, the difference between percent changes in the treatment and control knee for each session was examined to access the effect of KT application. The percent change in TTF at various KT application durations (0 hours, 24 hours, 48 hours, 72 hours) were compared for the treatment knee and the control knee within each subject (Figure 22). Initial observations at 0 hours of duration (Figure 22a) showed seven out of fourteen subjects had a greater improvement in the treatment knee, while a larger improvement was observed in the control knee in the other seven subjects. After 24 hours only four subjects 2, 3, 4, 7 showed greater improvements in the treatment knee compared to the control, while ten subjects exhibited more improvement in TTF in the control knee (Figure 22b). At 48 hours, four subjects 3, 5, 7, 8 showed a greater improvement in the treatment knee, and ten subjects had more improvement in the control knee (Figure 22c). The last duration at 72 hours showed the same improvement trend observed at 24 and 48 hours, nine subjects showing greater increases in TTF in the control knee compared to only four subjects 2, 3, 7, 8 showing greater TTF improvements in the treatment knee (Figure 22d). The results indicate that subjects showed an improvement in TTF during fatiguing exercise across sessions regardless of the application of KT treatment, supporting the observation that the improvement in TTF was primarily due to the learning effect.

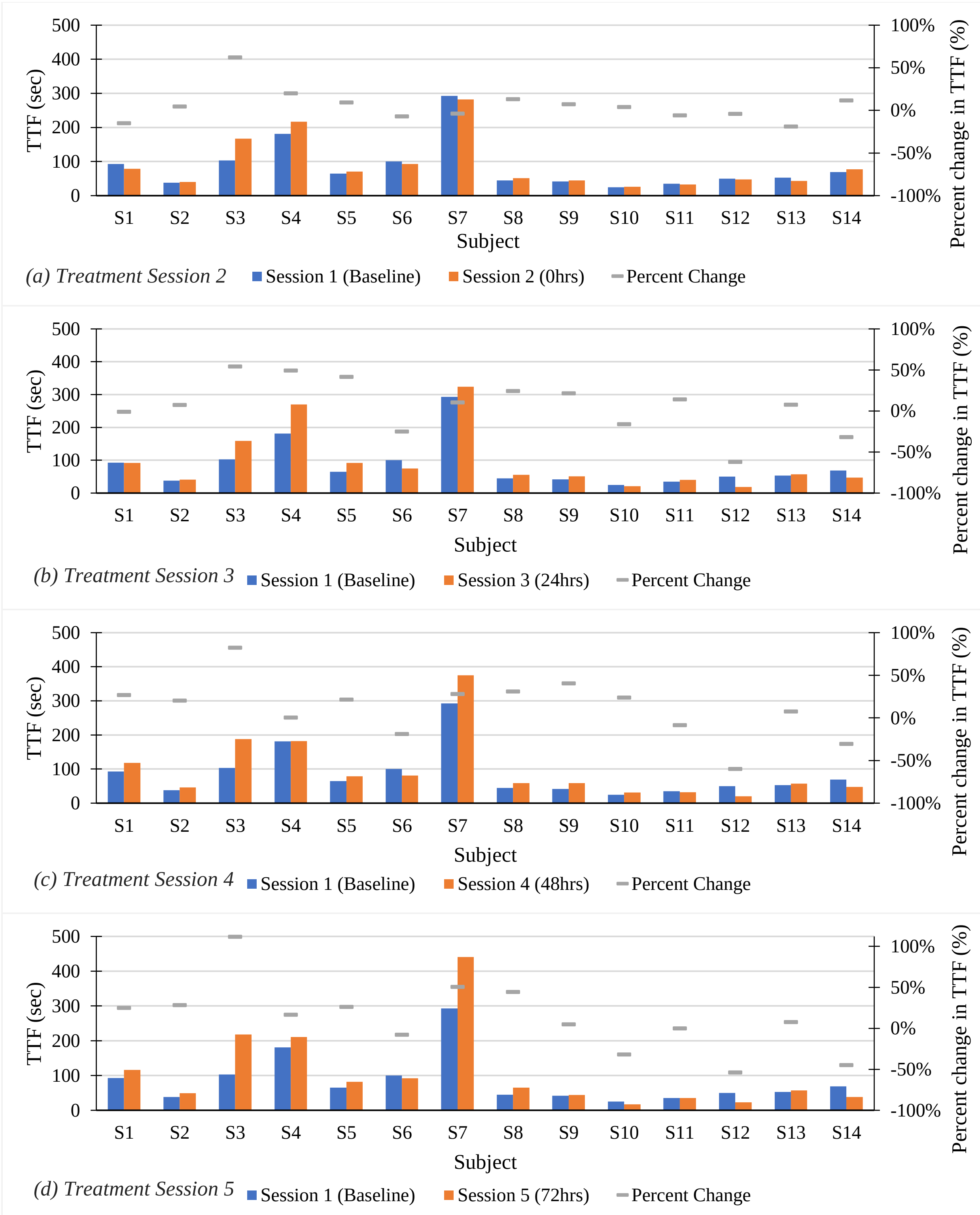


Figure 20. The percent changes in TTF of the treatment knee (%). Separate pairwise comparisons were performed between session 1 and sessions 2, 3, 4, and 5, where (a) session 1 to session 2, duration = 0 hrs.; (b) session 1 to session 3, duration = 24 hrs.; (c) session 1 to session 4, duration = 48 hrs., (d) session 1 to session 5, duration = 72 hrs.

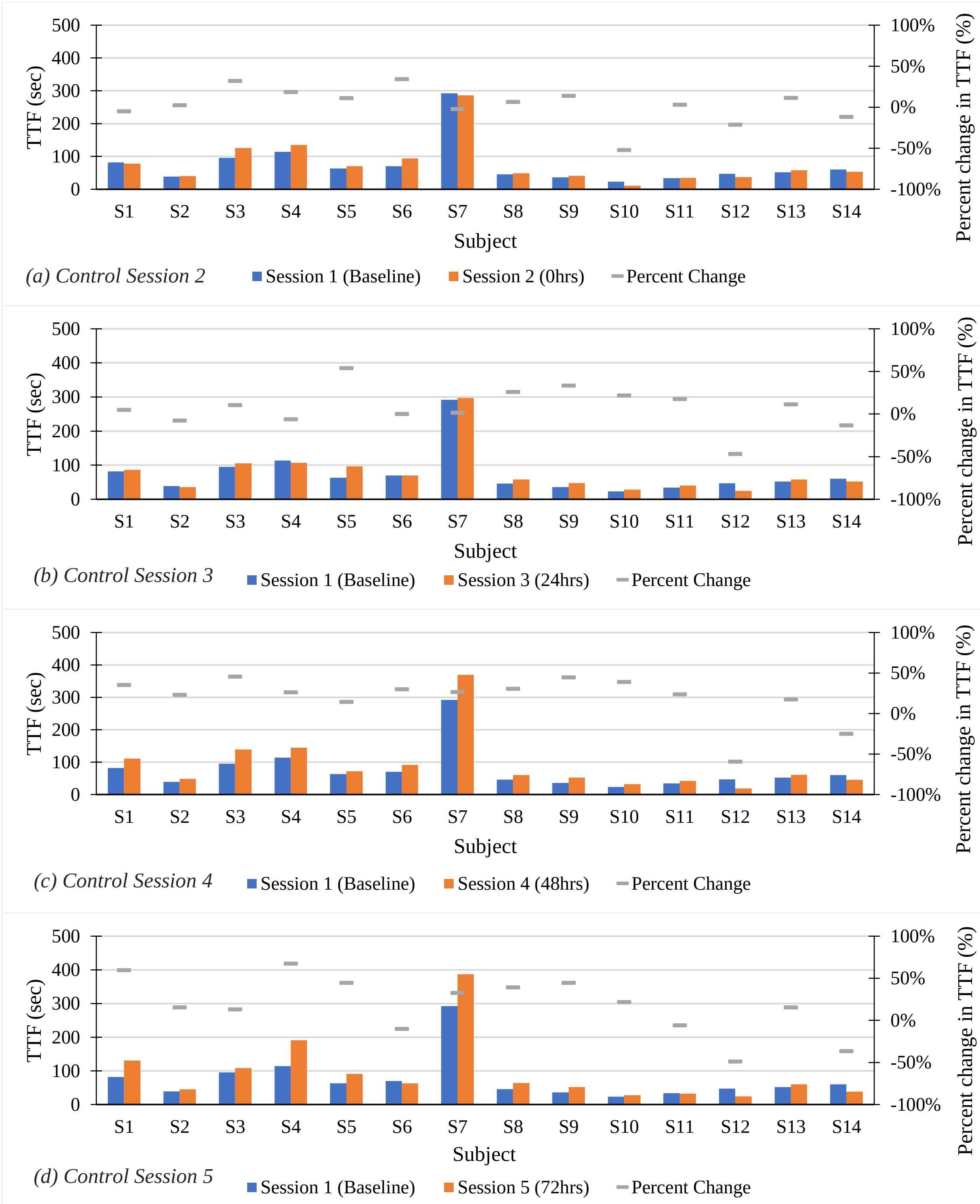


Figure 21. Percent changes in TTF in the control knee. Separate pairwise comparisons were performed between session 1 and sessions 2, 3, 4, and 5, where (a) session 1 to session 2, duration = 0 hrs.; (b) session 1 to session 3, duration =sider staffing 24 hrs.; (c) session 1 to session 4, duration = 48 hrs., (d) session 1 to session 5, duration = 72 hrs.

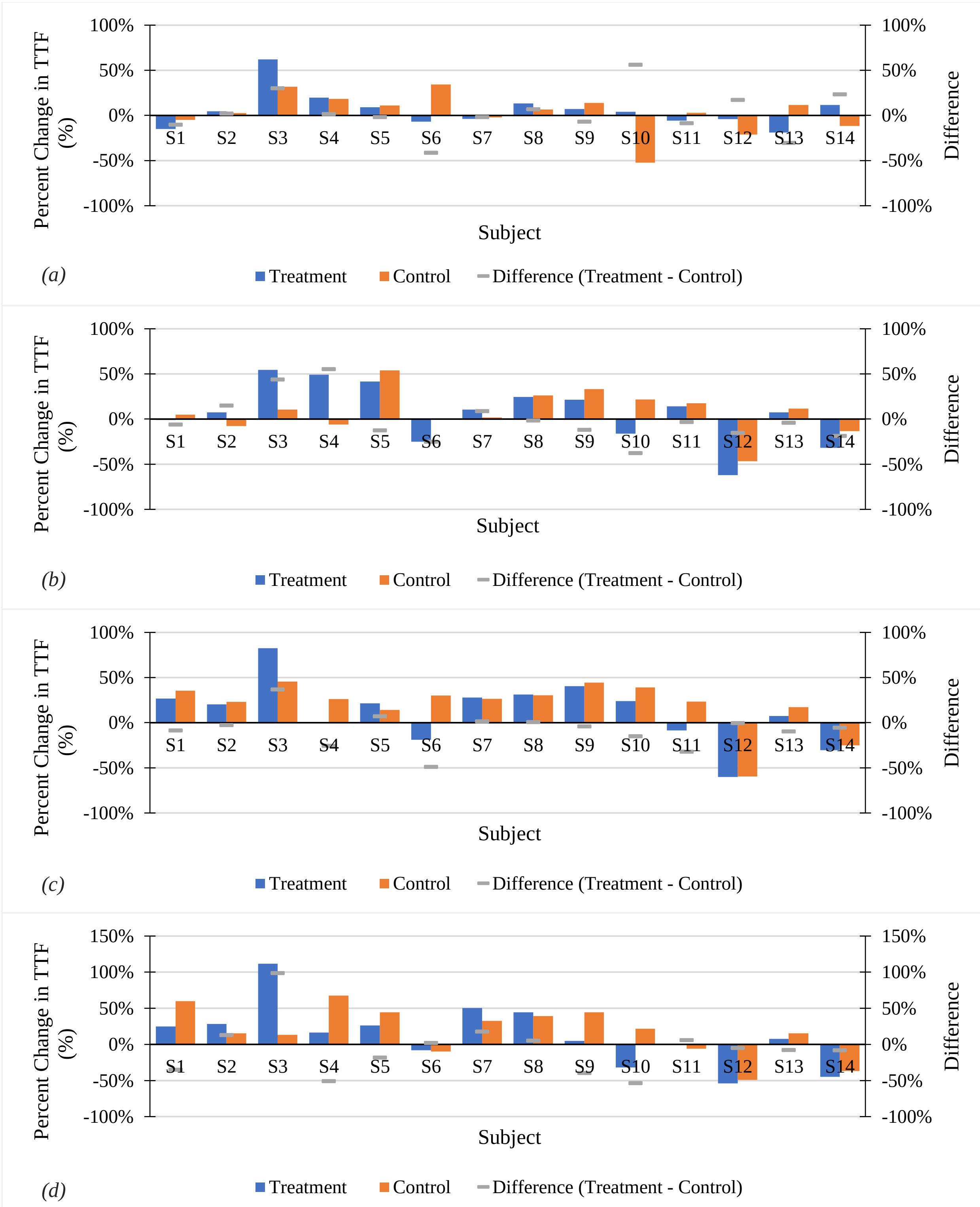


Figure 22. Percent changes in TTF between knees. By comparing the percent changes in treatment knee subtracted from percent changes of the control knee within subjects at each time duration: (a) 0 hours; (b) 24 hours; (c) 48 hours; and (d) 72 hours.

A continued increase in TTF was observed (24 hours and 48 hours) after the removal of KT application in sessions 6 and 7 in the treatment knee. TTF increased 20.89 sec (±28.00) on average in sessions 6, with subjects 4 and 6 experiencing a dramatic increase in TTF. Specifically, subject 4 had an increase of 105 seconds in TTF, and subject 6 has an increase of 49 seconds in TTF. Six subjects 1, 3, 7, 10, 13, 14 had moderate increases in TTF in session 6 compared to session 5, while another six subjects 2, 5, 8, 9, 11, 12 had a minimal increase in TTF. In session 7 after subjects had removal of KT for 48 hours, TTF still increased 10.07 sec (±17.67) on average compared to session 5. Remarkably, six subjects 2, 3, 5, 8, 12, 14 had higher increments in TTF in session 7 compared to session 6 (Figure 23a).

In the similar trend of treatment knee, the control knee also showed a gradual increase in TTF in the last two sessions 6 and 7. Compared to session 5, an increase of 9.65 sec (±24.75) on average was observed in sessions 6 and 10.30 sec (±23.31). for Session 7 for the control knee. Subject 7 had a dramatic increase of 88 seconds in TTF for the control knee in session 6 compared to session 5, and subject 4 had a large increase of 67 seconds in TTF in the control knee in session 7 over session 5 (Figure 23b).

It was noteworthy that all fourteen subjects reached their peak values in TTF in sessions 6 and 7 instead of sessions 2 to 5. The peak values were expected in sessions 2 to 5 during the application duration for the treatment knee. However, the peak values in TTF were observed in sessions 6 and 7 when the KT had been removed for 24 hours and 48 hours (Figure 24a). This indicated that the growth in TTF was not predominantly due to the treatment but rather a factor of time performing the task, that is, a learning effect. A steady increase in TTF was also observed in sessions 6 and 7 in the control knee (Figure 24b).

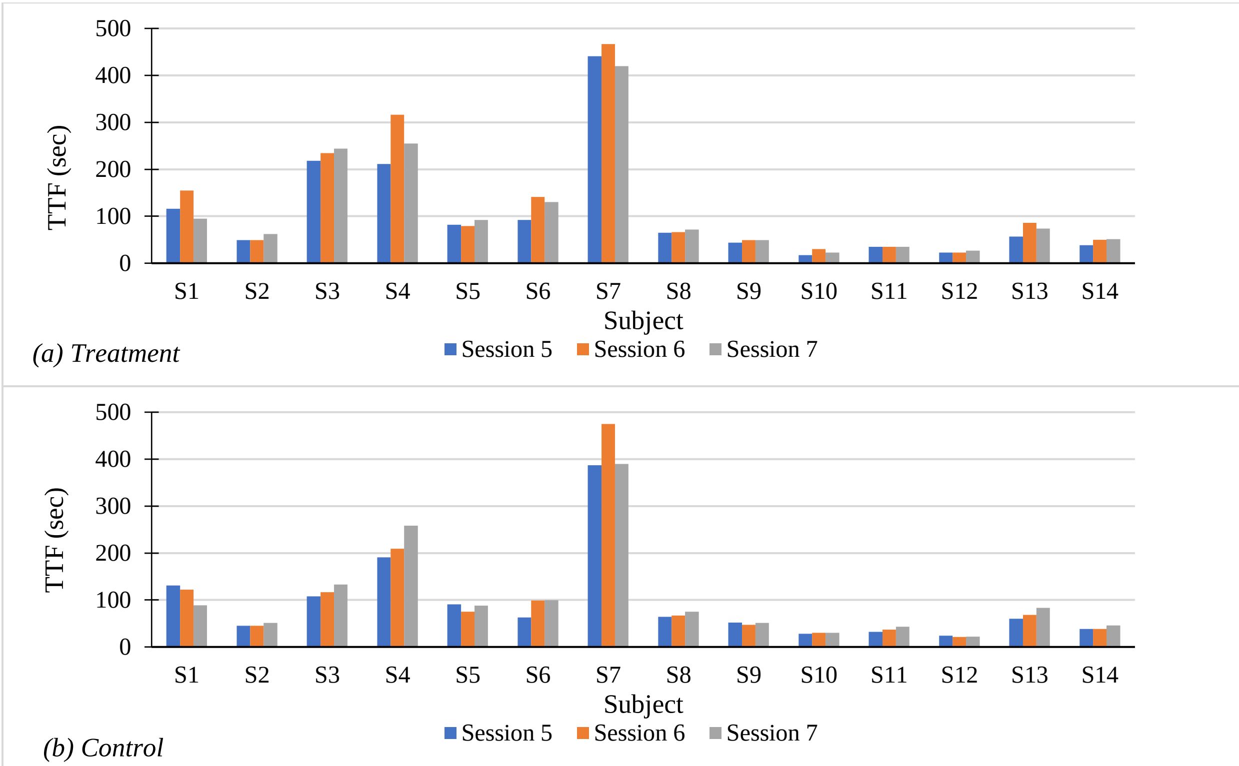


Figure 23. TTF in sessions 6, 7 compared to the last application session 5 in the treatment knee and control knee

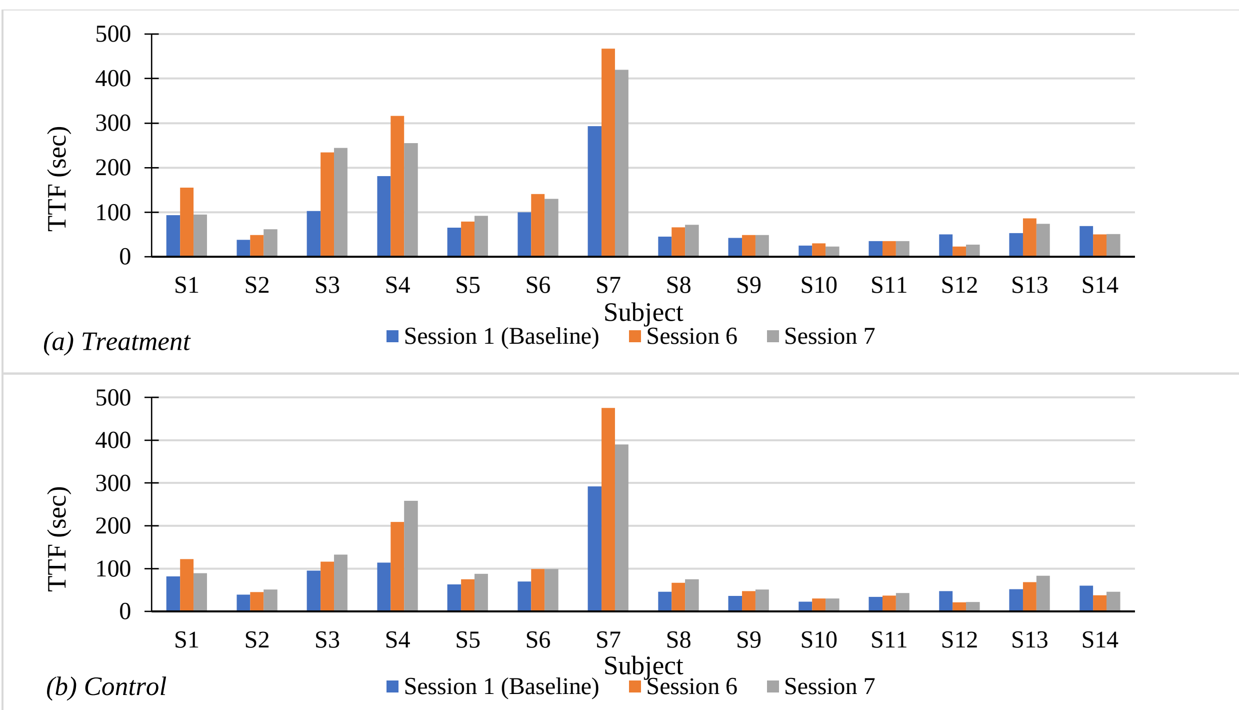


Figure 24. TTF in sessions 6 and 7 compared to the baseline session in the treatment knee and control knee

3.2.2 Number of Cycles

It was hypothesized that the longer KT was applied the larger the increase in the number of cycles that would be achieved. An average increase of 12.44% (±32.57%) across sessions was found (Figure 25a). The percent changes in the number of cycles ranged from a 52.08% decrease to an increase of 116.86% in the treatment knee. There were two subjects 3 and 7 who experienced a dramatic increase in the number of cycles across sessions. Six subjects 1, 2, 5, 8, 9, 11 had slight increases in the numbers of cycles, and six subjects that had minimal growth in the number of cycles across application durations (subjects 4, 6, 10, 12, 13, 14) (Figure 26). The effect of KT application durations on the percent change in number of cycles was not statistically significant because of the large variation in results between subjects (p = 0.381).

Learning effect was hypothesized to result in an increase of number of cycles during knee isotonic flexion/extension fatiguing exercise the control knee. The result showed that control knee had an overall increase of 14.16% (±27.17%) on average in the number of cycles (Figure 25b). The percent change in the number of cycles in the control knee ranged from a 65.00% decrease to a 74.36% increase. There were 12 subjects 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 13 that had a gradual increase in the number of cycles across sessions, and two subjects 12 and 14 who experienced consistent decreases across sessions (Figure 27). Learning effect was found to be statistically significant on the increase in the number of cycles (p = 0.023) for the control knee.

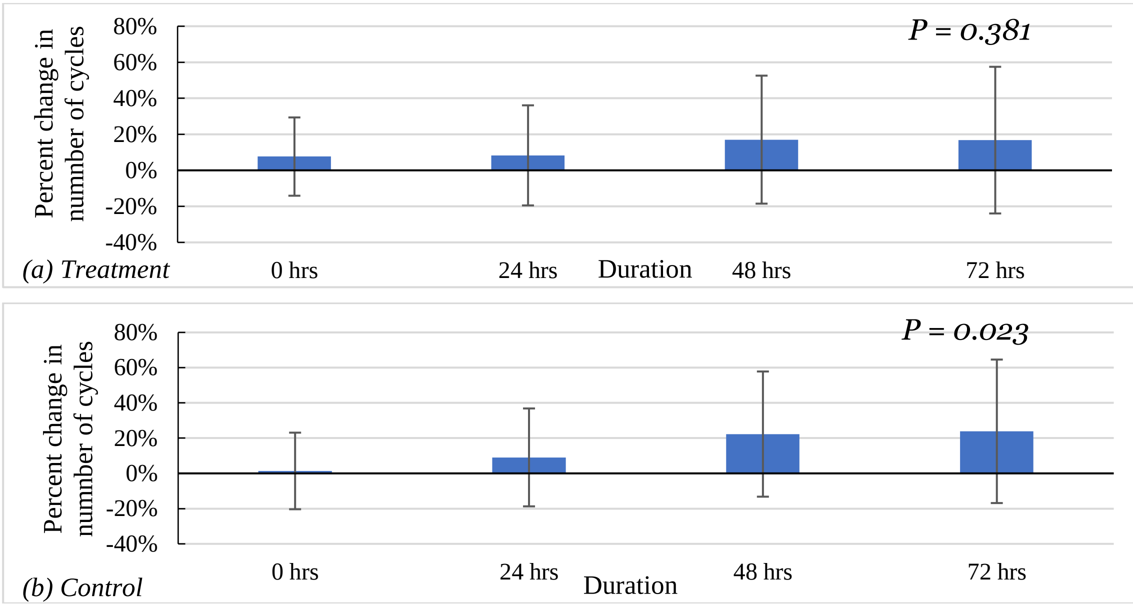


Figure 25. The average and the standard deviation of percent changes in the number of cycles of (a) treatment knee and (b) control knee (%) are presented in each duration session

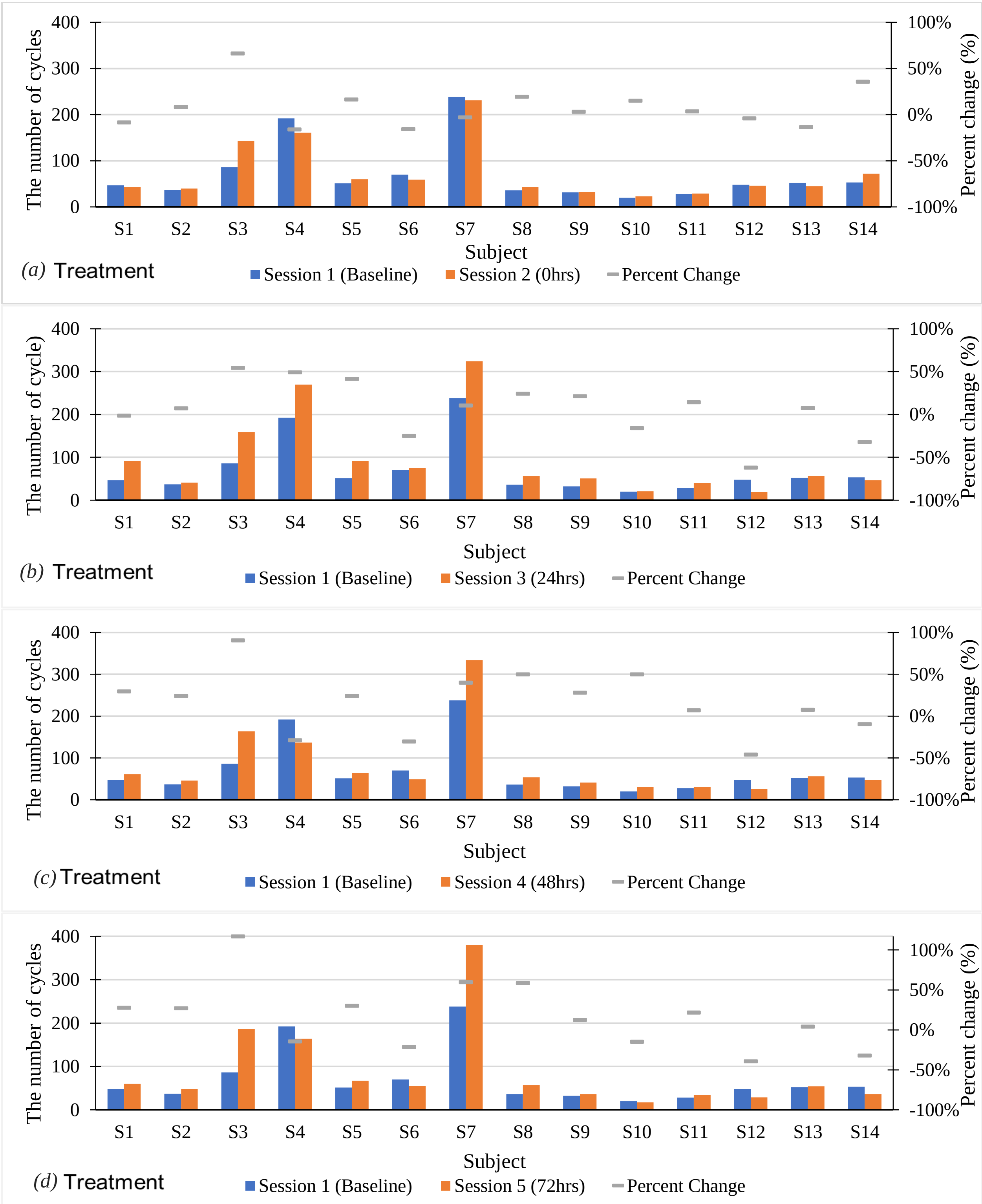


Figure 26. The number of cycles from session 1 to session 2, 3, 4, 5 in the treatment knee. Separate pairwise comparisons were performed between session 1 and sessions 2, 3, 4, and 5, where (a) session 1 to session 2, duration = 0 hrs.; (b) session 1 to session 3, duration = 24 hrs.; (c) session 1 to session 4, duration = 48 hrs., (d) session 1 to session 5, duration = 72 hrs.

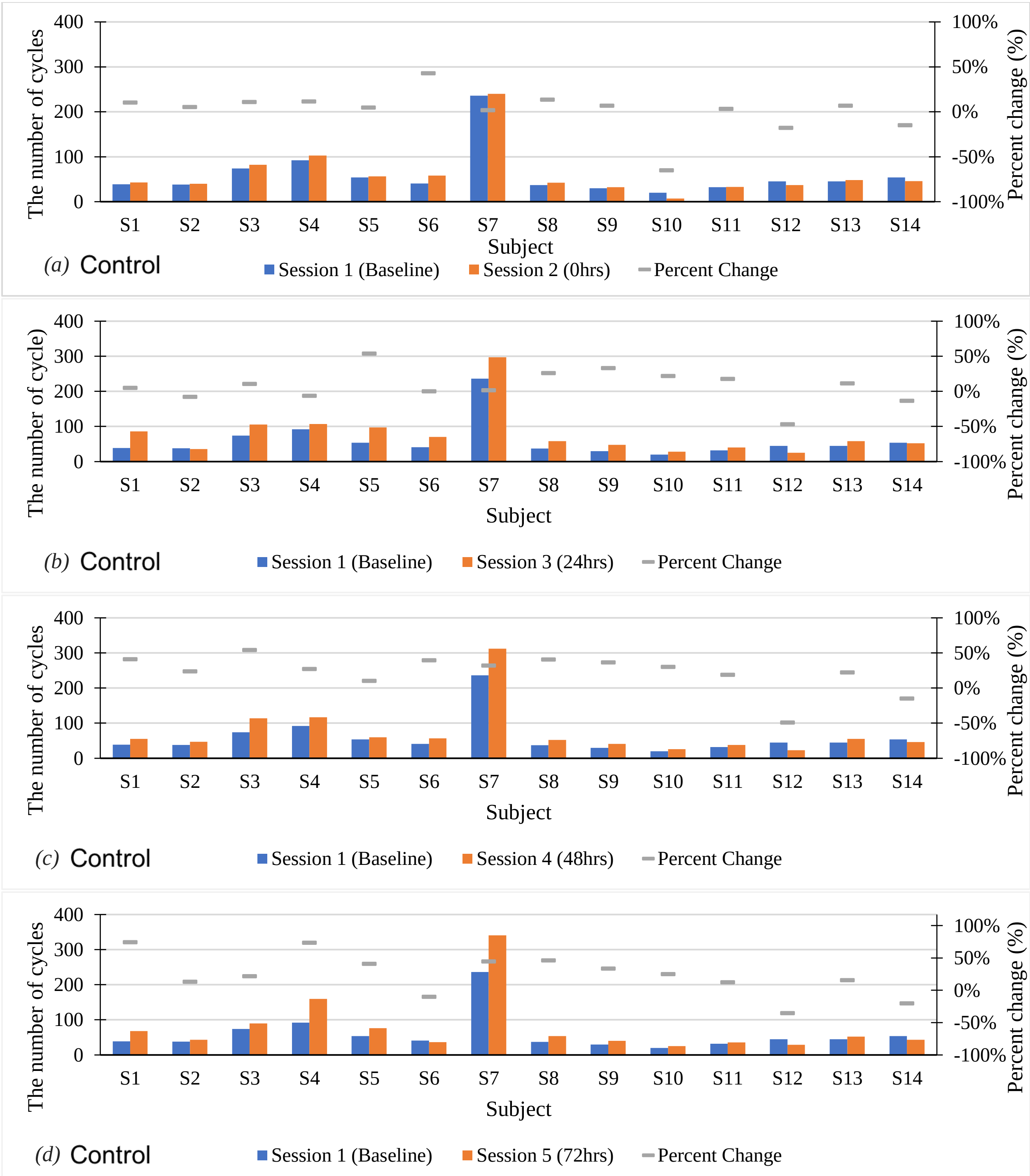


Figure 27. The number of cycles from session 1 to session 2, 3, 4, 5 in the control knee. Separate pairwise comparisons were performed between session 1 and sessions 2, 3, 4, and 5, where (a) session 1 to session 2, duration = 0 hrs.; (b) session 1 to session 3, duration = 24 hrs.; (c) session 1 to session 4, duration = 48 hrs., (d) session 1 to session 5, duration = 72 hrs.

A learning effect was distinctly noted in the number of cycles (Figure 28). This indicates that the observed increase in number of cycles in the treatment knee could also be at least partially explained by the learning effect. Among the 12 subjects who had consistent gradual increases in the number of cycles in the control knee (subjects 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 13), 9 subjects had a similar increase in the treatment knee (subjects 1, 2, 3, 5, 7, 8, 9, 10, 11, 13). Since a learning effect was observed in the control knee, the significance of KT application was also investigated by examining the difference in percent changes between the treatment and control knees. Contrary to expectation, the control knee showed a larger increase in the number of cycles than did the treatment knee within five subjects 1, 4, 6, 9, 13 across sessions. Only two subjects 3 and 7 showed a larger increase in the number of cycles in the treatment knee compared to the control knee. There were 5 subjects 2, 5, 8, 10, 11 who had similar increases in the number of cycles for the treatment and control knees across sessions. Three subjects 6, 12, 14 did not have the increase in the number of cycles in their treatment knee.

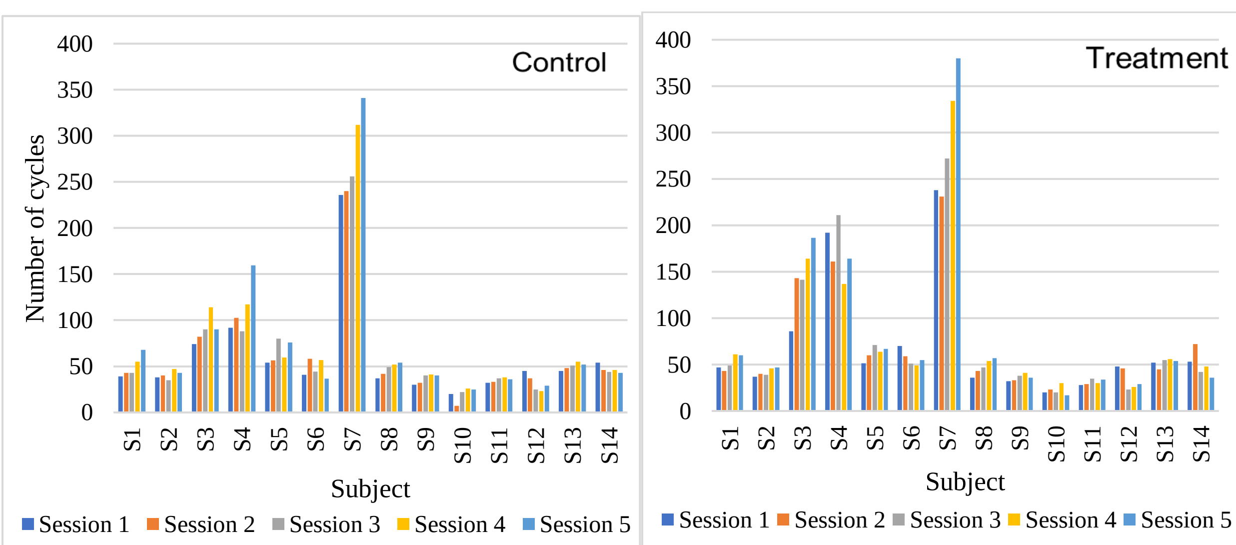


Figure 28. The learning effect was observed in both knees without KT application across five sessions

A continual increase in the number of cycles was noticed in sessions 6 and 7 in the treatment knee (Figure 29). Seven subjects 1, 4, 6, 7, 10, 13, 14 obtained their peak values of number of cycles in session 6. Six subjects 2, 3, 5, 8, 9, 12 made their highest records of number of cycles in session 7.

The continual increase in the number of cycles in the treatment knee in sessions 6 and 7 is similar to the outcome in the control knee, where it was noted that 9 out of 14 subjects (2, 3, 4, 6, 7, 8, 9, 10, 13) reached their maximum number of cycles in sessions 6 and 7. This observed gradual increment of values in both treatment and control knee was likely due to the learning effect. Kinesio tape application appears to have been irrelevant to the subjects reaching the maximum number of cycles.

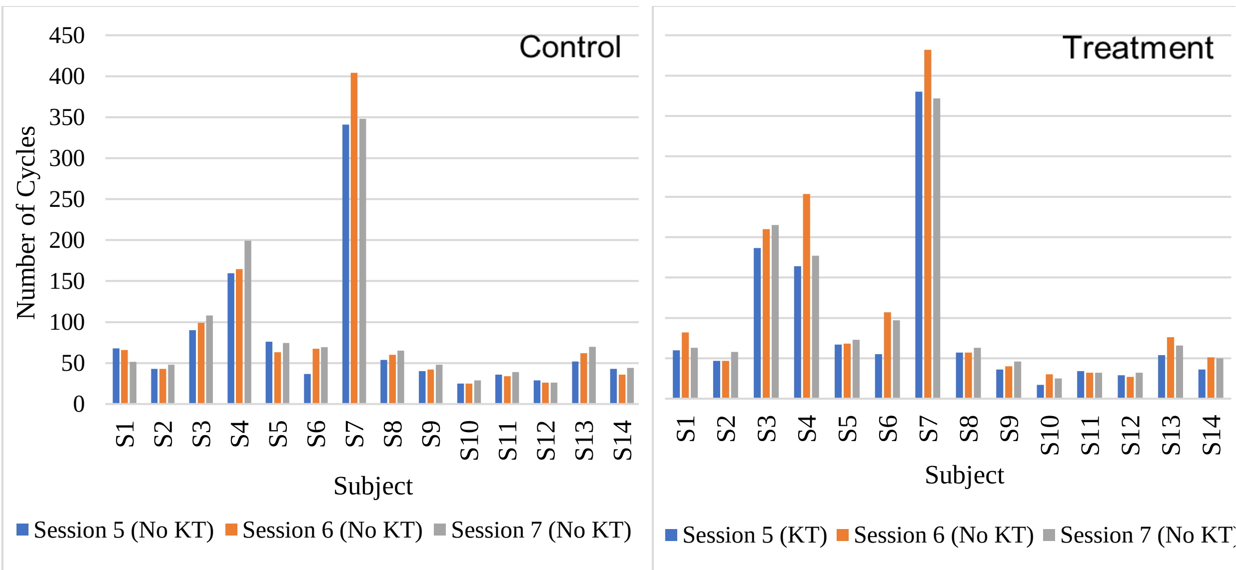


Figure 29. Number of cycles observed in both treatment knee and control knee in sessions 5, 6, and 7

3.2.3 Muscle Oxygenation

3.2.3.1 Time to Minimum rSO_2 (TTM rSO_2)

It was hypothesized that application durations of KT will result in delay of time to minimum muscle rSO_2 during knee isotonic flexion/extension fatiguing exercise. The hypothesized TTM rSO_2 would increase across sessions. The percent difference from sessions 2, 3, 4, and 5 using KT versus session 1 without KT were compared to investigate the potential effect of KT application durations on delaying TTM rSO_2 (Table 7).

Table 7. Average and standard deviation of percent changes in TTM for each 24-hour increment of duration

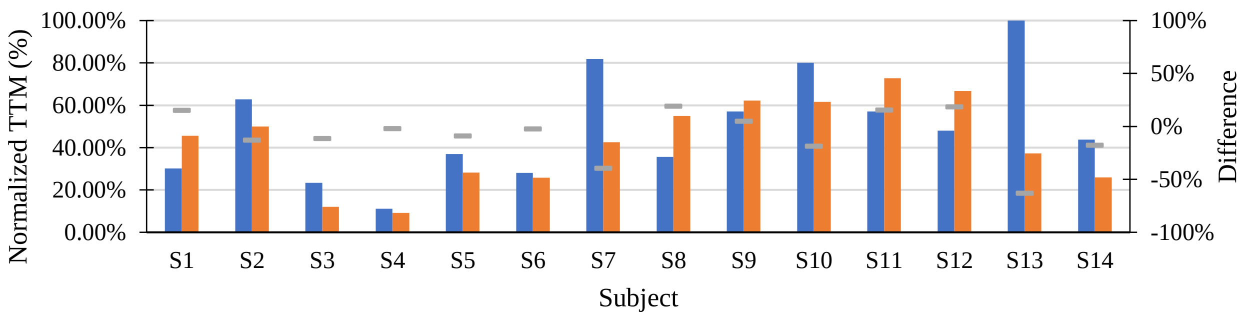
Duration of KT application (hrs.)	Vastus Lateralis (Treatment)			Vastus Lateralis (Control)		
	Mean (SD) %	(Min, Max) %	*p*-value	Mean (SD) %	(Min, Max) %	*p*-value
0 (Immediate)	-7.22 (22.40)	(-62.79, 19.35)	0.778	-7.17 (20.47)	(-58.97, 30.43)	0.181
24	-3.44 (27.61)	(-64.91, 37.17)		-0.02 (21.02)	(-53.49, 57.75)	
48	-2.66 (25.15)	(-57.89, 52.00)		-6.03 (24.70)	(-74.77, 71.77)	
72	-1.01 (18.15)	(-29.30, 52.00)		-8.36 (24.95)	(-72.52, 41.06)	
Duration of KT application (hrs.)	Vastus Medialis (Treatment)			Vastus Medialis (Control)		
	Mean (SD) %	(Min, Max) %	*p*-value	Mean (SD) %	(Min, Max) %	*p*-value
0 (Immediate)	-0.50 (15.29)	(-42.67, 28.31)	0.234	1.26 (12.67)	(-15.81, 32.61)	0.226
24	3.58 (12.98)	(-22.71, 31.24)		8.54 (15.82)	(-16.67, 48.94)	
48	-0.35 (14.29)	(-31.22, 29.38)		-1.50 (14.54)	(-28.21, 33.15)	
72	4.76 (17.41)	(-18.83, 49.57)		4.34 (21.55)	(-22.53, 48.94)	

Although It was hypothesized that application durations of KT could delay TTM rSO_2, there was a great variation in the change of TTM rSO_2 in application durations. The changes in TTM rSO_2 ranged from a 64.91% decrease to an increase of 37.17% for VL and from a reduction of 22.71% to an increase of 31.24% for VM (Table 7).

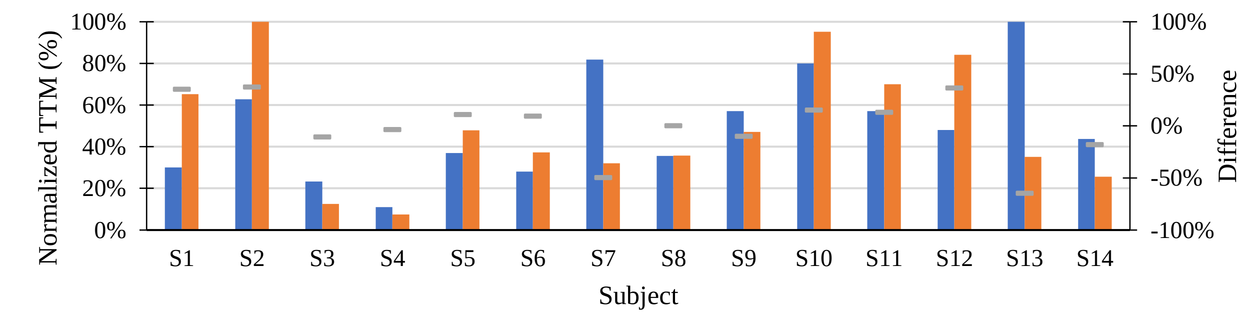
In session 3, 8 subjects 1, 2, 5, 6, 8, 10, 11, 12 experienced an increase in TTM rSO_2 for VL (Figure 30b), and 9 subjects 1, 2, 3, 4, 6, 10, 11, 13, 14 had an observed delay in TTM rSO_2 for VM (Figure 32b). It was noted that the increase in TTM rSO_2 was not consistent with the change in TTF, with only subject 11 who had delay in TTM rSO_2 in both VL and VM also showing an increase in TTF. The 3 subjects 3, 4, 7 who had an dramatic increase in TTF did not have a delay in TTM rSO_2 of VL.

In sessions 4, it was noted that the reduced TTM rSO_2 was connected with an increase in TTF. Nine out of the ten subjects who had increases in TTF in session 4 (subjects 1, 3, 4, 5, 7, 8, 9, 10, 13) had decreased TTM rSO_2 in VL (Figure 30c). All 6 subjects who had a decrease in TTM of VM (subjects 1, 3, 5, 7, 8, 9) had an increase in TTF in session 4.

In session 5, seven out of nine subjects who had increases in TTF (subjects 1, 2, 3, 5, 7, 8, 13) had decreases in TTM rSO_2 of the VL. All 7 subjects who had a decrease in normalized TTM rSO_2 for the VM (subjects 1, 2, 3, 5, 7, 8, 9) had an increase in TTF in session 5. It was noted that subjects experienced delays in TTM rSO_2 for VM during application periods, however, this did not consistent as the result of physical performance which showed delay in fatigue. There was no statistically significant delay in TTM rSO_2 observed in the VL and VM for prolonged KT application (p = 0.778 and p = 0.234).



(a) Treatment VL



(b) Treatment VL

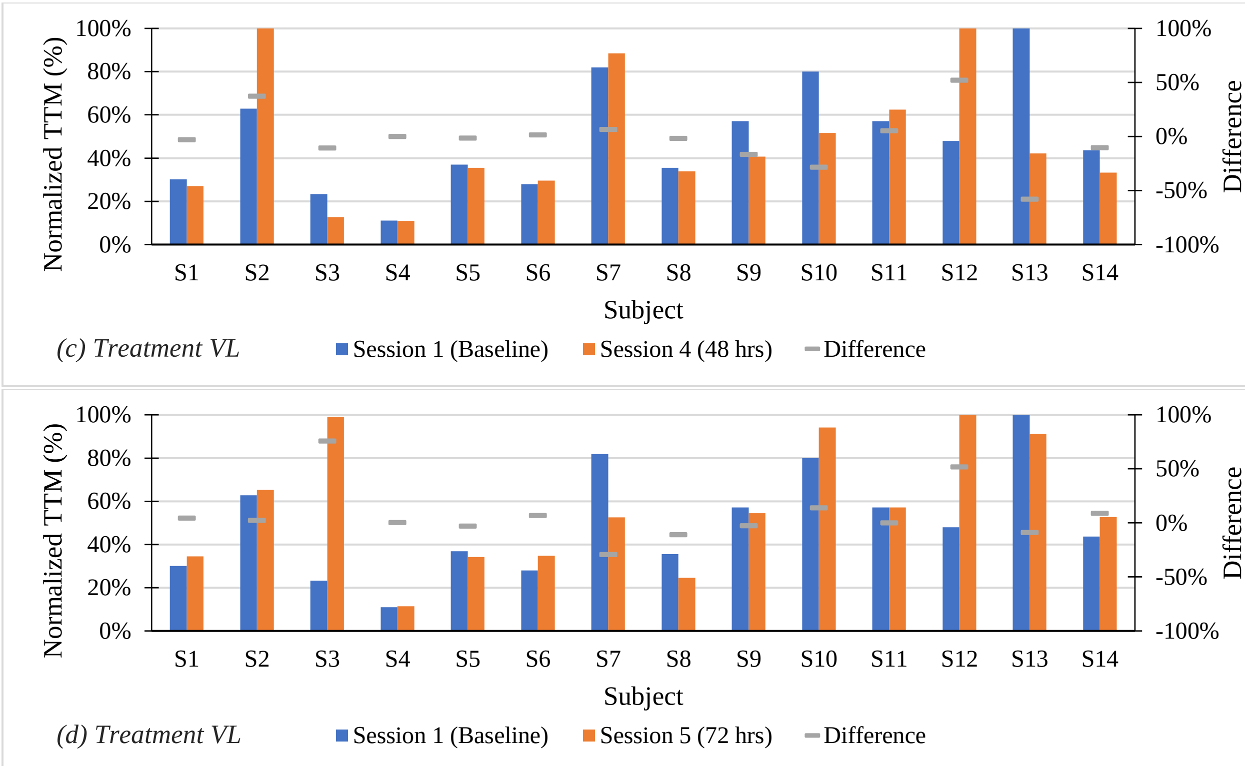
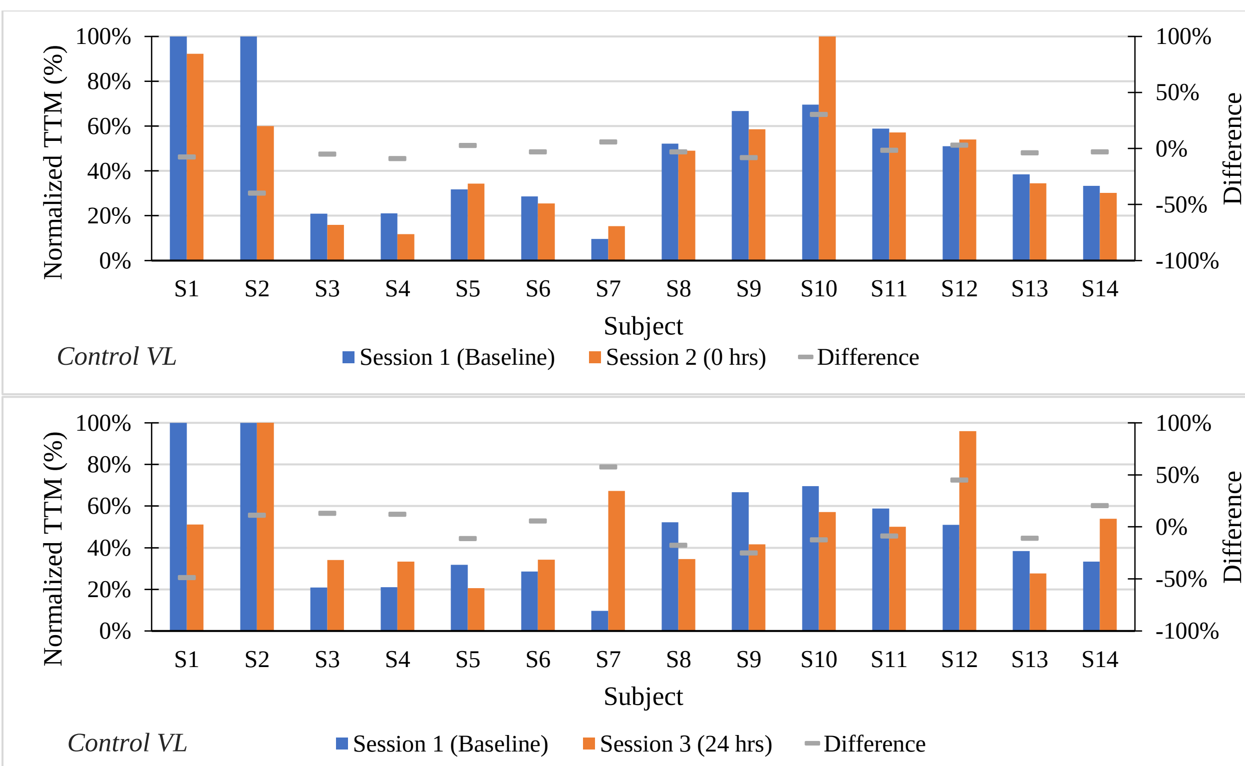
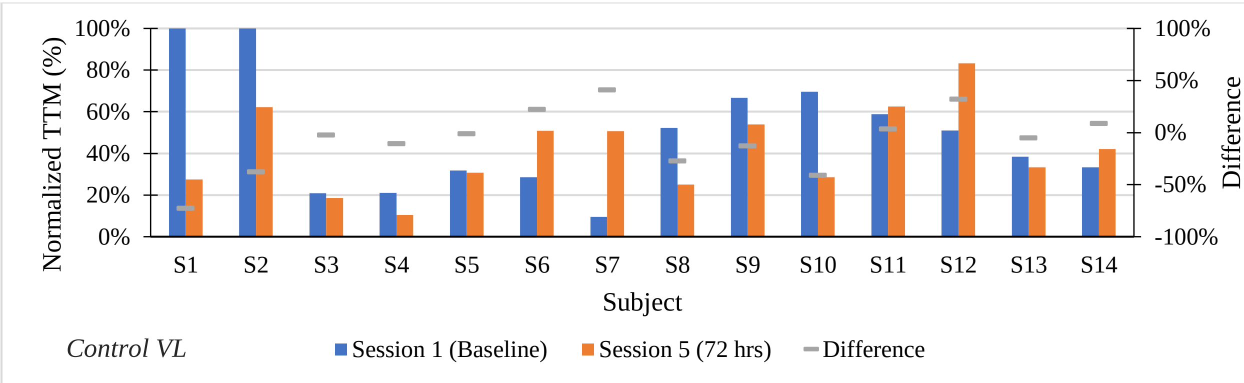


Figure 30. The normalized time to minimum rSO_2 for VL from session 1 to session 2, 3, 4, 5 in the treatment knee. There was no consistent delay in TTM. Separate pairwise comparisons were performed between session 1 and sessions 2, 3, 4, and 5, where (a) session 1 to session 2, duration = 0 hrs.; (b) session 1 to session 3, duration = 24 hrs.; (c) session 1 to session 4, duration = 48 hrs., (d) session 1 to session 5, duration = 72 hrs.





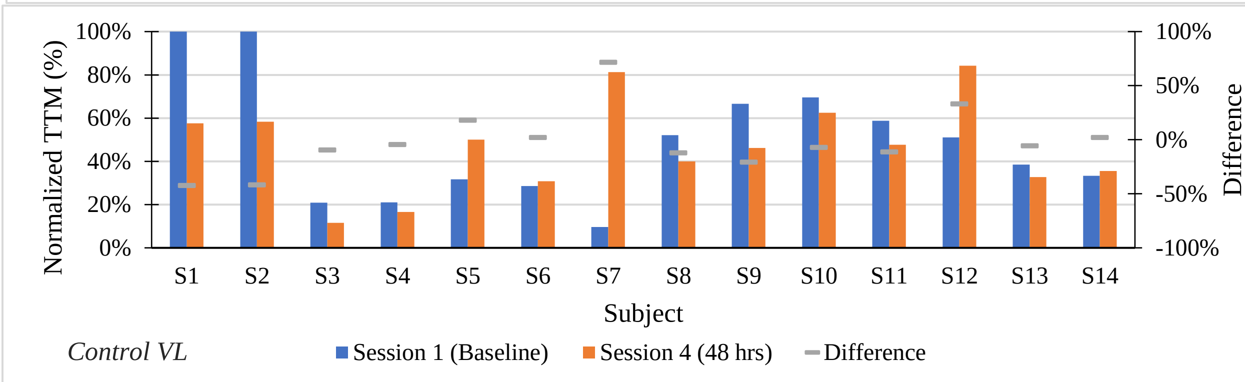
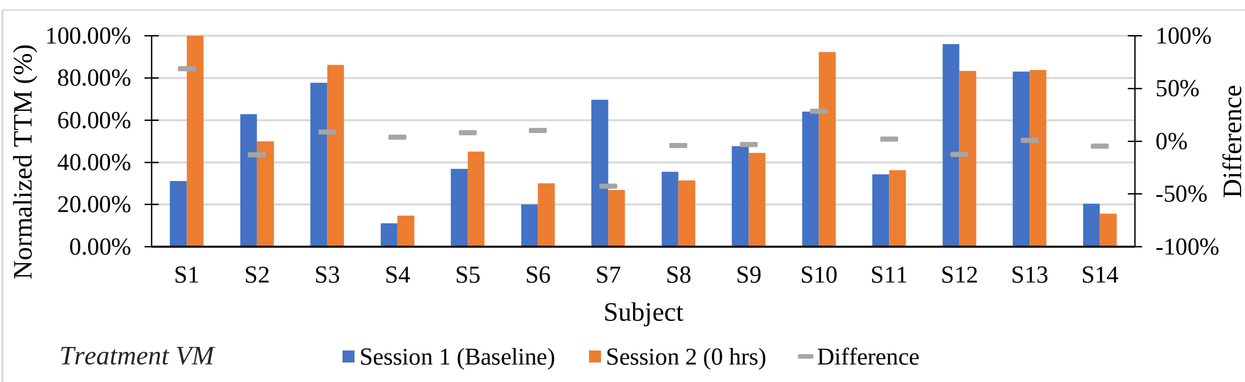
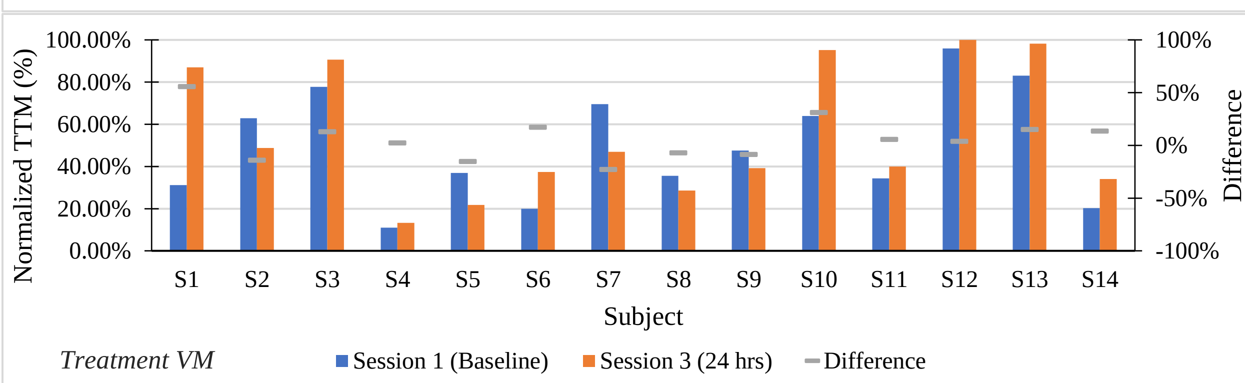


Figure 31. The delay in normalized time to minimum rSO_2 for VL was not seen in the control knee across sessions for most subjects.





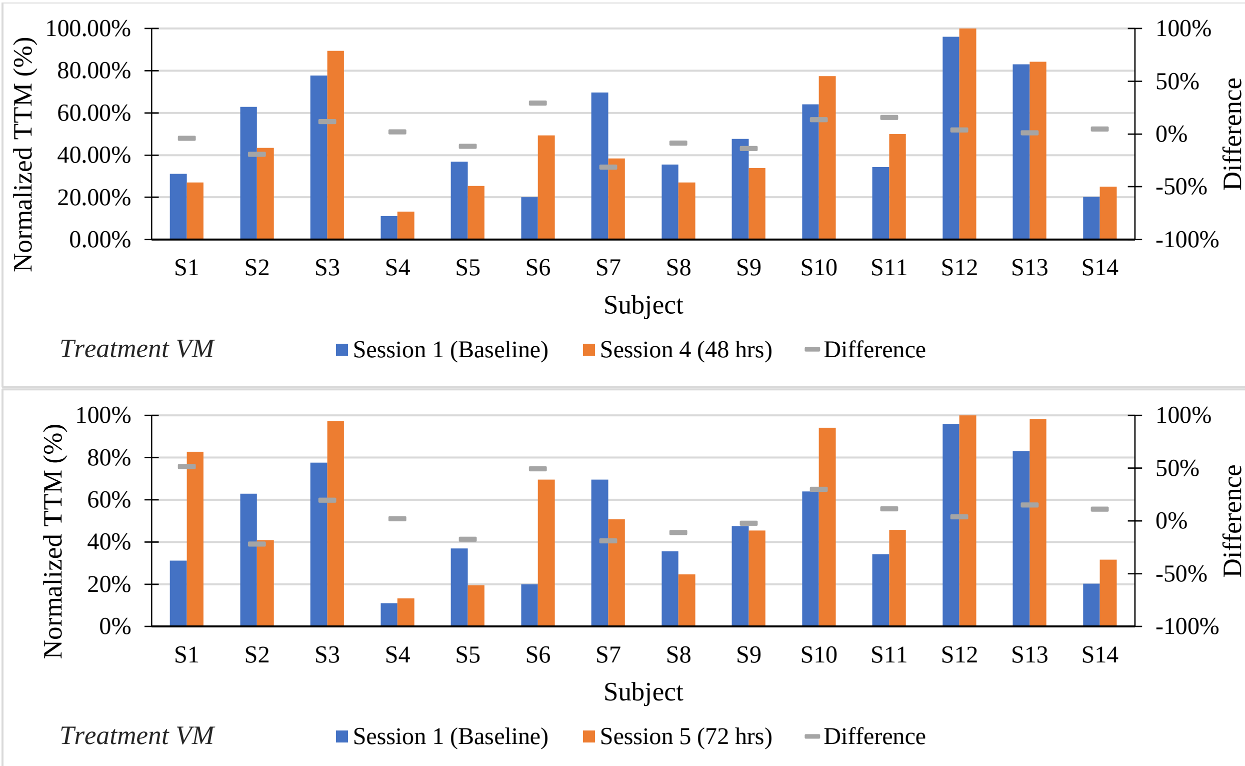
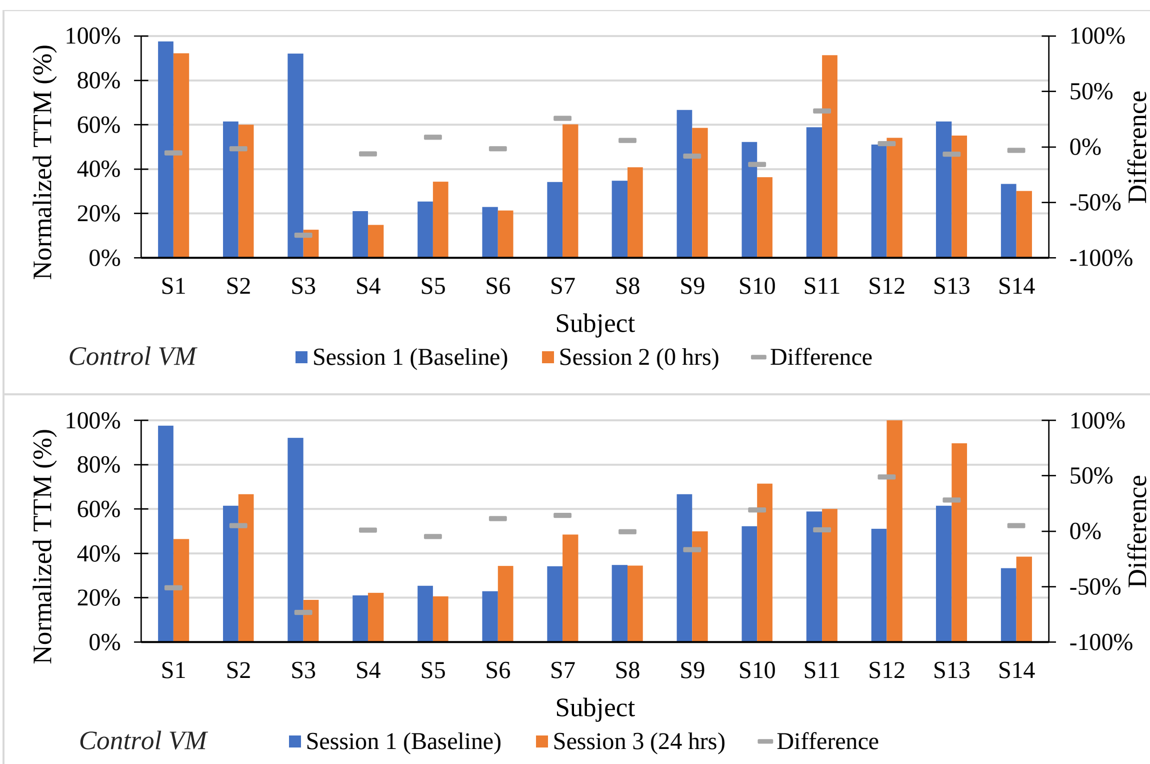


Figure 32. The normalized time to minimum rSO_2 for VM from session 1 to session 2, 3, 4, 5 in the treatment knee. Although the increase in normalized TTM of VM was observed for some subjects during application durations, TTF was not delayed for those subjects.



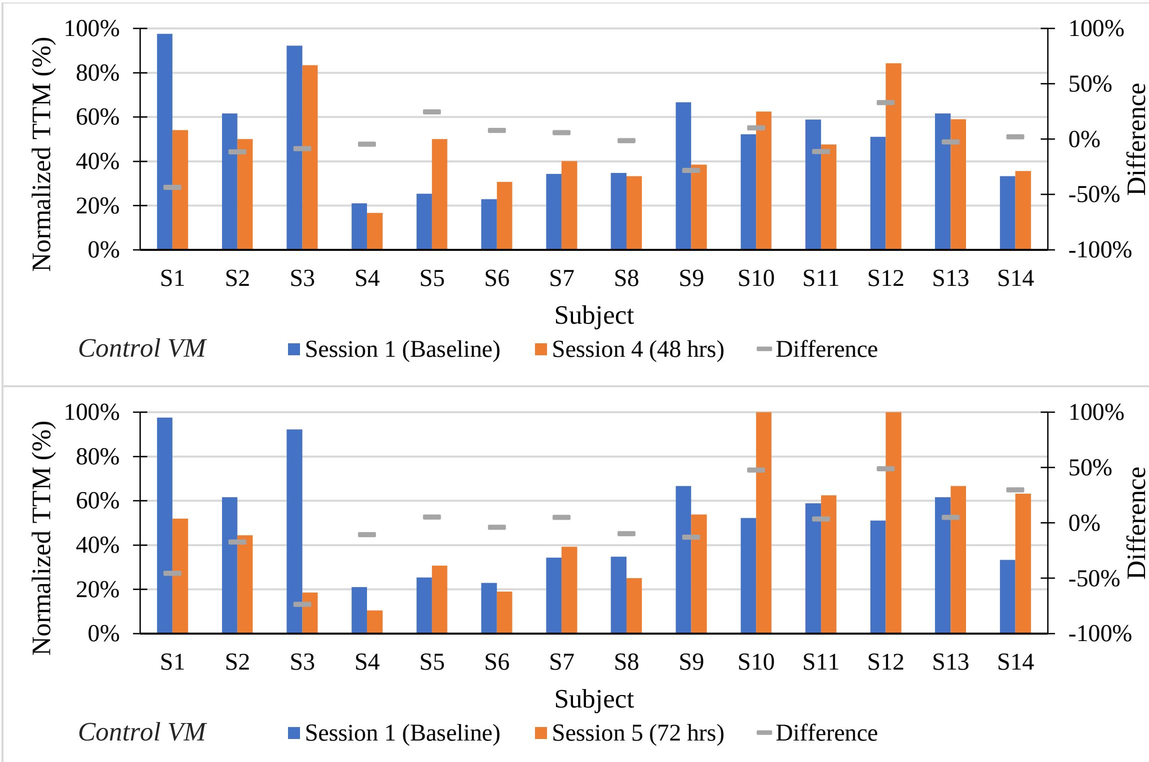


Figure 33. The normalized time to minimum rSO_2 for VM from session 1 to session 2, 3, 4, 5 in the control knee. The increase in TTM was also observed in the control knee, however, the increase in TTM of VM did not positively corelate with the delay in TTF.

There was also no substantial change in TTM rSO_2 for either muscle, VL or VM, in the treatment knee after the removal of KT in sessions 6 (Figure 34). TTM rSO_2 in VL decreased by 6.51% (±23.69) on average in session 6 with no KT applied. For VM, TTM also had a decrease of 1.10% (±15.73) on average in session 6. Eight out of fourteen subjects 1, 3, 4, 6, 7, 8, 10, 13 who had a decrease in TTM in VL had an increase in TTF. Nine out of fourteen subjects 1, 3, 4, 5, 6, 7, 8, 10, 13 who had a decrease in TTM for VM had an increase in TTF. The increase in TTF was observed to coincide with a decrease in normalized TTM in session 6.

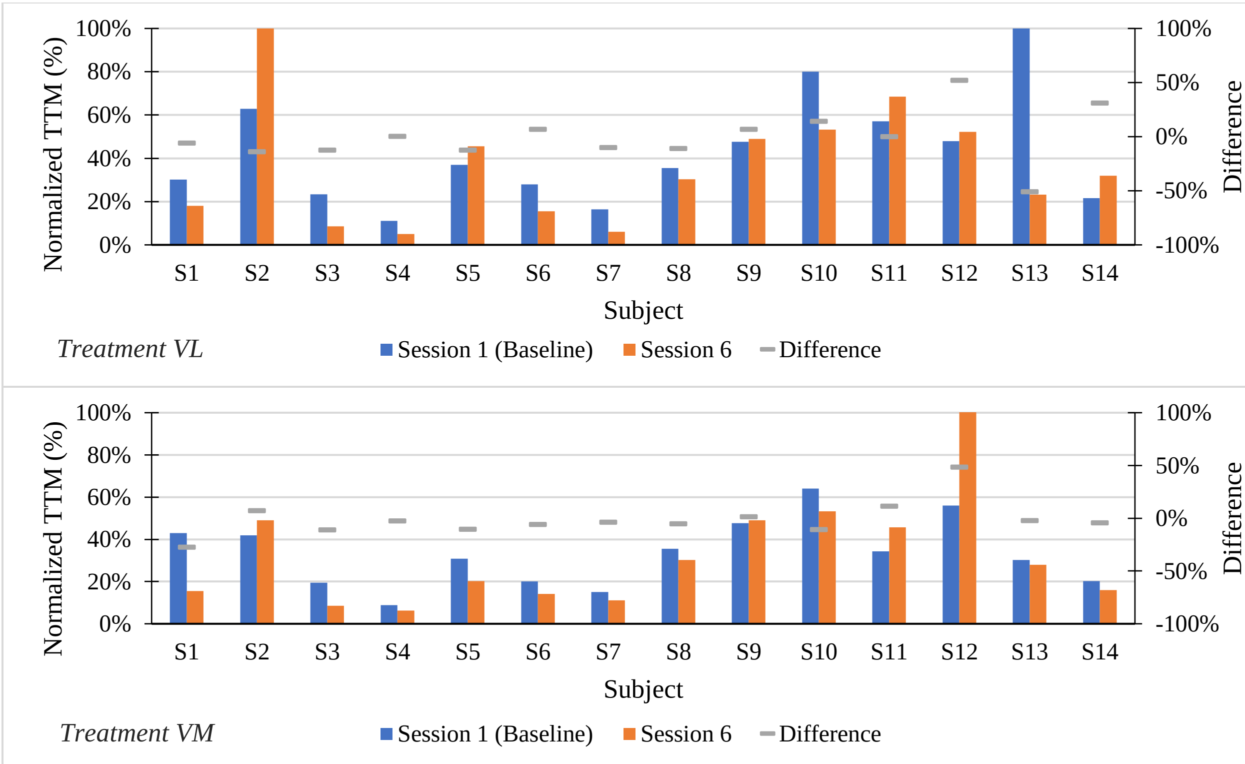


Figure 34. Time to minimum oxygenation level in the treatment knee in the post-application session 6 compared to session 1

In session 7, while most subjects had an increase in TTF, normalized TTM rSO_2 for VL and VM were observed to decrease (Figure 35). TTM decreased by 11.09% (±16.68%) for VL and by 2.86% (±10.32%) for VM on average in session 7. Ten out of fourteen subjects 1, 2, 3, 4, 5, 6, 7, 8, 9, 13 who had an increase in TTF also had a decrease in VL. Nine out of fourteen subjects 1, 2, 3, 4, 6, 7, 8, 9, 13 had a decrease in TTM for VM and an increase in TTF. The only two subjects 12 and 14 who had a slight increase in TTM for VL (Figure 35) had a reduction of TTF in session 7.

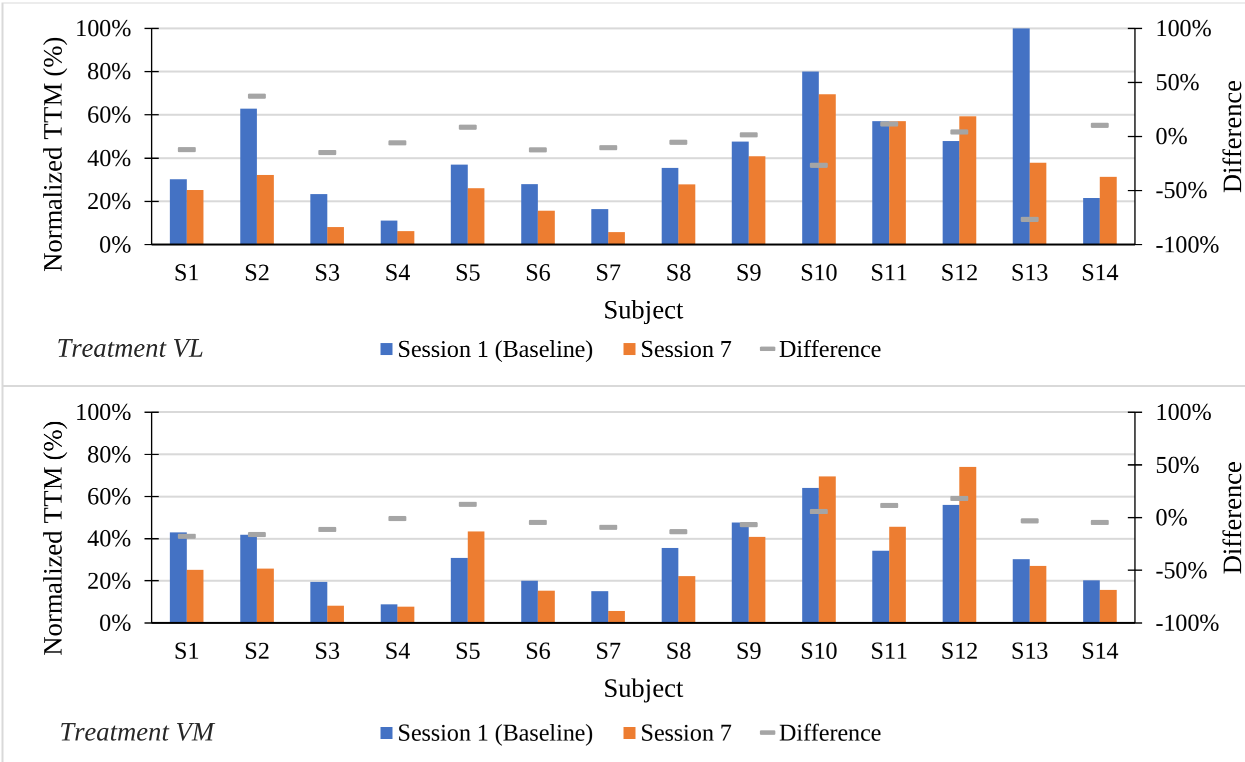
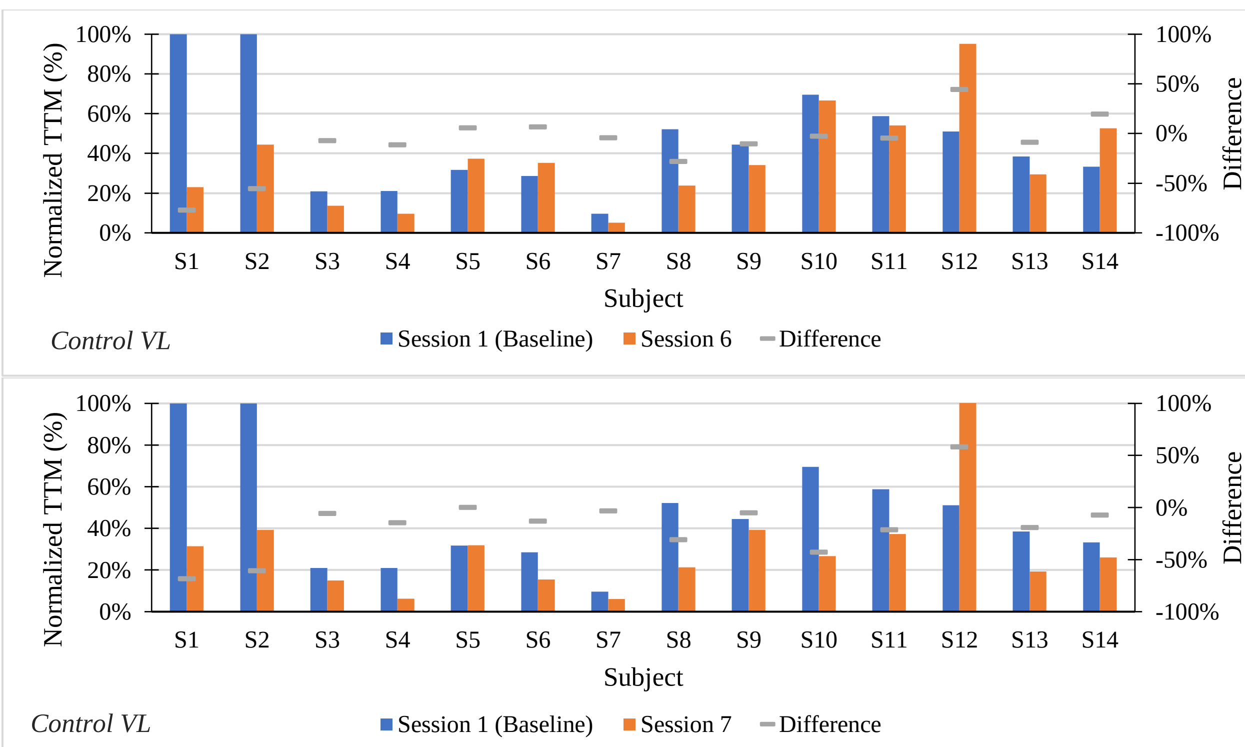


Figure 35. Time to minimum oxygenation level in the treatment knee in the post-application session 7 compared to session 1

It was also hypothesized that learning effect will result in delay of time to minimum muscle rSO_2 during knee isotonic flexion/extension fatiguing exercise. However, a delay in TTM of VL was also not observed in the control knee in session 3(Figure 36). Seven out of the nine subjects who had increases in TTF in session 3 (subjects 1, 3, 5, 7, 8, 9, 10, 11, 13) had decreased TTM in VL, and the other two subjects who had increase in TTF slowed down their rate of flexion and extension. In session 4, except for two subjects who reduced their cycle rate, the other nine subjects had a decrease in TTM in VL and had a delay in TTF (subjects 1, 2, 3, 4, 7, 8, 10, 11, 13). In session 5, ten out of eleven subjects who had increase in TTF had a decrease in TTM of VL. The control knee results showed that TTM was decreased by 7.72% (±23.16%) in VL but increased by 1.48% (±15.99%) in VM on average across 5 sessions. The measured change in TTM was also not statistically significant for the control knee in the VL or VM (p = 0.745 and p = 0.960), with a large variation observed between subjects ranging from -72.52% to 44.94% and -22.53% to 57.45% for the VL and VM.

Eight out of twelve subjects 1, 2, 3, 4, 7, 8, 9, 11 who had an increase in TTF had reduced normalized TTM in both VL and VM in the control knee in session 6 (Figure 36). Nine subjects 1, 2, 3, 4, 6, 7, 8, 11, 13 had a decreased TTM for both VL and VM and an increase in TTF in session 7. Subject 12 was the only one who had increased TTM for both VL and VM overall but did not have any increase in TTF. The average change in TTM in the control knee was a reduction of 9.68% (±27.49%) in session 6 and a continued reduction of 16.82% (±28.22%) in session 7 for VL. The average change in TTM for VM was -1.85% (±17.00%) in session 6 and 0.31% (±21.41%) in session 7. There was no substantial change in normalized TTM for VM in the control knee in session 6 and 7 compared to the baseline session.



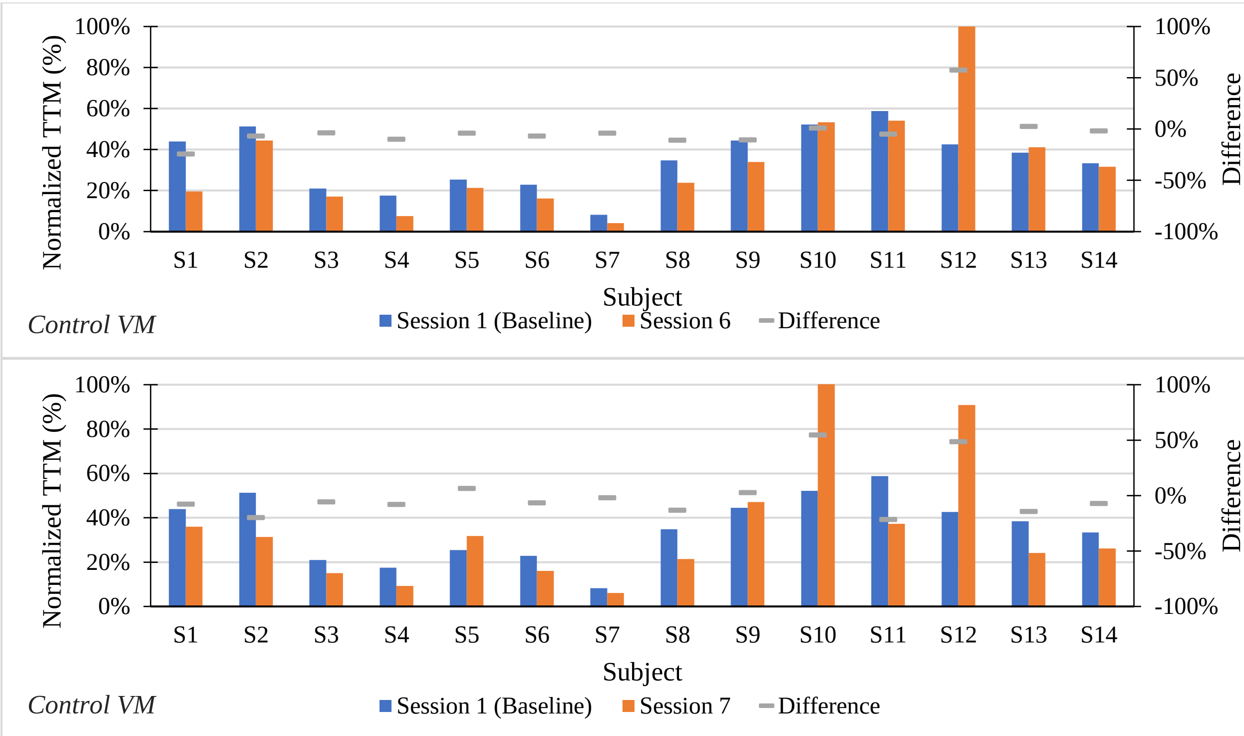


Figure 36. Change in time to minimum oxygenation level in the control knee in sessions 6 and 7 compared to baseline session.

3.2.3.2 Rate_rSO_2

The potential for the effect of duration of the KT application to reduce rate_rSO_2 was also investigated by comparing sessions 2, 3, 4, and 5 after applying KT with session 1 (Figures 37). Application durations of KT was hypothesized to reduce the drop of muscle rSO_2 rate during knee isotonic flexion/extension fatiguing exercise. Rate_rSO_2 ranged between 0.06 and 3.24 in the VL and between 0 and 2.47 per second in the VM of the treatment knee. For the VL muscle, rate_rSO_2 had an increase of 0.07 per second (±0.48) on average across sessions and VM rate_rSO_2 was increased by 0.05 per second (±0.40) on average.

The General Linear Model shows that there was no significant reduction within subject in rate_rSO_2 for VL and VM (p = 0.786, p = 0.611, respectively) in the treatment knee. However, there was a substantial difference in rate_rSO_2 between subjects. Subject 12 had a dramatic increase in drop rate of rSO_2 in both VL and VM across sessions. Subjects 2, 5, 8 and 9 had a decreasing drop rate in rSO_2 across sessions. Other subjects did not have a consistent increase or decrease in drop rate of rSO_2 across application durations. The change in rate_rSO_2 was between -0.45/sec and +2.34/sec for the VL and between -0.29/sec and +1.89/sec for the VM.

Learning effect was also hypothesized to reduce the drop of muscle rSO_2 rate during knee isotonic flexion/extension fatiguing exercise. In the control knee, there was still a great variation between subjects, rate_rSO_2 over the sessions ranged from 0.01/sec to 2.78/sec in the VL and from 0 to 2.32/sec in the VM. Rate_rSO_2 had an increase of 0.04/sec (±0.38) on average for VL across sessions and for VM rate_rSO_2 also increased by 0.04/sec (±0.26) on average. The result of rate_rSO_2 in the control knee was noted to experience a learning effect over the duration.

There was also no significant change within subject in rate_rSO_2 for either the VL or the VM (p = 0.635 and 0.391, respectively) in the control knee. Moreover, drop rate of rSO_2 had a large difference between subjects (Table 8). Subject 12 had a relatively high increase in rate_rSO_2 of both muscles compared to other subjects. Subjects 1, 2, 8, and 9 had a decrease in rate_rSO2 of VL across sessions which was similar to the change in the treatment knee. The results show that change in rate_rSO_2 ranged between -0.47/sec and +1.72/sec for the VL and between -0.17/sec and +1.75/sec for the VM in the control knee. Compared to the treatment knee, the control knee had a slightly larger decrease in rate_rSO_2 for most subjects. This result is consistent with the result of TTF in that the learning effect is more clearly seen in the control knee as compared to the treatment knee.

Table 8. Change in rate_rSO_2 for each 24-hour increment of duration

Duration of KT application (hrs.)	Vastus Lateralis (Treatment)			Vastus Lateralis (Control)		
	Mean (SD)	(Min, Max)	*p*-value	Mean (SD)	(Min, Max)	*p*-value
0	0.01 (0.14)	(-0.25, 0.24)	0.786	-0.02 (0.14)	(-0.19, 0.37)	0.635
24	0.11 (0.60)	(-0.41, 2.17)		0.07 (0.37)	(-0.40, 0.92)	
48	0.12 (0.64)	(-0.45, 2.80)		-0.08 (0.50)	(-0.40, 1.72)	
72	0.05 (0.36)	(-0.37, 1.12)		0.03 (0.40)	(-0.47, 1.07)	
Duration of KT application (hrs.)	Vastus Medialis (Treatment)			Vastus Medialis (Control)		
	Mean (SD) %	(Min, Max) %	*p*-value	Mean (SD) %	(Min, Max) %	*p*-value
0	-0.01 (0.13)	(-0.22, 0.26)	0.611	-0.01 (0.09)	(-0.17, 0.25)	0.391
24	0.10 (0.51)	(-0.25, 1.89)		0.02 (0.11)	(-0.16, 0.29)	
48	0.08 (0.49)	(-0.29, 1.78)		0.11 (0.46)	(-0.17, 1.75)	
72	0.03 (0.32)	(-0.26, 1.09)		0.01 (0.17)	(-0.14, 0.52)	

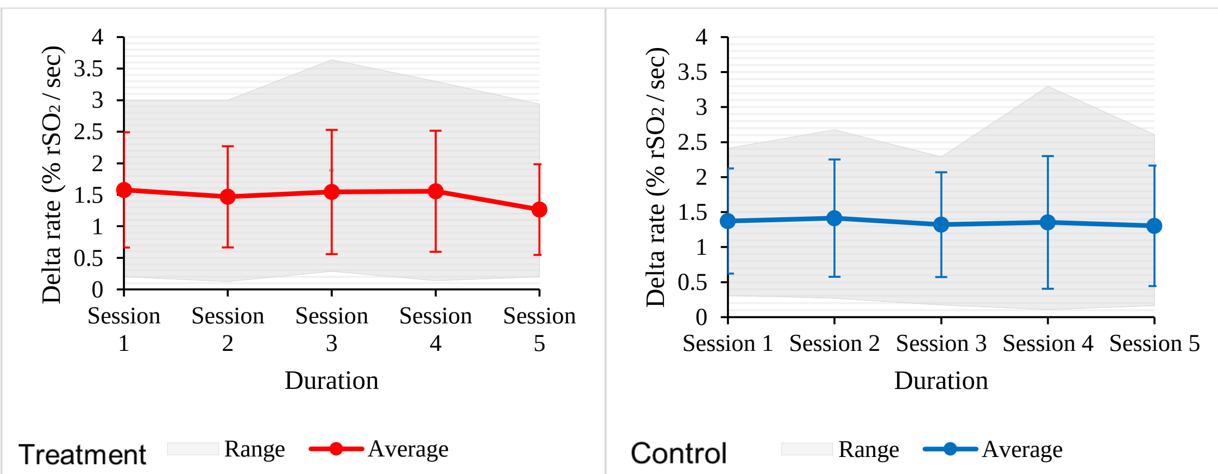


Figure 37A: rSO_2 drop rate of VL of the treatment knee for each testing session. Figure 37B: rSO_2 drop rate of control knee for each testing session. The shadowed area indicates a corridor (range between min and max values)

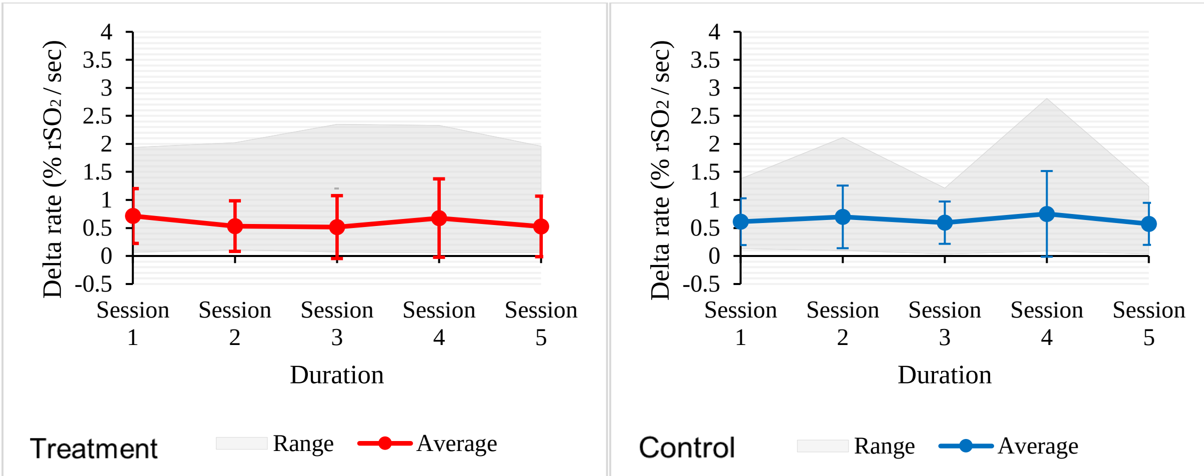


Figure 38A: rSO_2 drop rate of VM of the treatment knee for each testing session. Figure 38B: rSO_2 drop rate of VM of the control knee for each testing session. The shadowed area indicates a corridor (range between min and max values)

3.2.4 Muscle Activity

3.2.4.1 Electromyography Root Mean Square (EMG RMS)

It was hypothesized that application durations of KT will delay muscle fatigue during knee isotonic flexion/extension fatiguing exercise. There was a large difference in percent change in rate of RMS between subjects in treatment knee across the 4 application sessions. (Table 9).

In session 3 there was a continued decrease in average RMS in the treatment knee. A decrease in average RMS was observed in 8 subjects 1, 2, 4, 6, 9, 10, 11, 13 for VL (Figure 39), 12 subjects 1, 2, 3, 4, 5, 7, 8, 9, 10, 11, 12, 13 for VM (Figure 41), and 8 subjects for RF (subjects 1, 3, 4, 5, 8, 9, 10, 13) (Figure 43).

Learning effect was also hypothesized to delay muscle fatigue during knee isotonic flexion/extension fatiguing exercise. There was a large difference in the rate of RMS between subjects was observed in the control knee, and the percent change in rate of RMS ranged from -60.8% to 56.1% for VL, -49.1% to 19.2% for VM, and -60.7% to 21.83% for RF. A similar change was observed in the control knee. The control knee had a decrease in average RMS in 9 subjects 1, 3, 4, 5, 6, 8, 11, 12, 14 for VL (Figure 40), 13 subjects 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 13, 14 for VM (Figure 42), and 9 subjects for RF (subjects 3, 4, 6, 8, 9, 10, 12, 13, 14) in session 3 (Figure 44).

In session 4, both knees had similar numbers of subjects who had a decrease in average RMS for the VL and VM. Eight subjects 1, 3, 4, 5, 6, 9, 10, 11 had decreases in average RMS of VL in both knees. Subjects 7 and 12 had an increase in average RMS in VL of both knees. In VM, 8 out of 14 subjects 4, 5, 7, 9, 10, 11, 12, 13 had a decrease in average RMS for both knees. This similar decrease in RMS in the control knee compared to treatment knee indicates a potential learning effect. However, there was an increased number of subjects that had observed increased average RMS of RF in the treatment knee compared to prior sessions, with 8 subjects 2, 3, 4, 7, 8, 11, 12, 14 whose average RMS of RF increased in the treatment knee. There were 5 subjects 7, 8, 11, 12, 14) who had an increase in average RMS of RF in the control knee and the other 9 subjects had a decreased average RMS compared to baseline session.

In session 5 the learning effect still was noted. Seven subjects 1, 4, 5, 6, 8, 9, 10 had decreases in their average RMS in both knees for the VL (Figures 39 and 40) and 10 out of 14 subjects 1, 4, 5, 6, 7, 8, 9, 11, 12, 13 had decreased average RMS in both knees for VM (Figures 41 and 42). There were 9 subjects 1, 2, 3, 4, 5, 9, 10, 13 who had decreases in average RMS in RF for both knees (Figures 43 and 44).

There was no significant effect of KT application durations on the change in average RMS of VL, VM, and RF in the treatment knee (p = 776, p = 0.152, p = 0.730, respectively). There was also no substantial effect on decreasing the rate of change in RMS in the treatment knee (Table 10).

In the control knee, no substantial change was found in average RMS of VL, VM, and RF (p = 0.189, p = 0.695, p = 0.180, respectively). However, there was a significant learning effect for decreasing the rate of change in VL and RF of the control knee. There was a significant decrease in the rate of change in RMS of VL in sessions 4 and 5, and a great decrease in rate of change in RMS for RF in session 4 (Table 10). This indicated that the effect of KT application durations was not influential on delaying the muscle fatigue, but rather the changes were due to the learning effect, which included posture change and muscle synergy.

Table 9. Average and range of percent change in rate of change in RMS for each 24-hour increment of duration

Duration of KT application (hrs.)	VL (Treatment)			VL (Control)		
	Mean (SD)	(Min, Max)	*p*-value	Mean (SD)	(Min, Max)	*p*-value
0	-5.7 (22.8)	(-38.1, 46.6)	0.191	-6.8 (21.3)	(-30.9, 52.2)	0.000*
24	-15.0 (16.8)	(-46.8, 18.7)		-12.1 (25.3)	(-45.1, 56.1)	
48	-21.2 (17.2)	(-47.4, 19.8)		-29.2 (14.0)	(-45.2, -0.0)	
72	-19.1 (22.0)	(-47.0, 41.9)		-25.0 (22.0)	(-60.8, 13.8)	
Duration of KT application (hrs.)	VM (Treatment)			VM (Control)		
	Mean (SD) %	(Min, Max) %	*p*-value	Mean (SD) %	(Min, Max) %	*p*-value
0	-10.7 (18.1)	(-41.8, 23.1)	0.156	-16.1 (16.5)	(-44.2, 19.2)	0.077
24	-20.3 (22.8)	(-47.8, 35.6)		-19.0 (12.6)	(-39.3, 7.0)	
48	-24.9 (21.4)	(-51.5, 26.0)		-26.9 (12.2)	(-42.2, 6.6)	
72	-24.8 (31.6)	(-57.1, 70.8)		-26.8 (15.9)	(-49.1, -5.4)	
Duration of KT application (hrs.)	RF (Treatment)			RF (Control)		
	Mean (SD) %	(Min, Max) %	*p*-value	Mean (SD) %	(Min, Max) %	*p*-value
0	3.1 (33.0)	(-39.7, 91.5)	0.073	-4.8 (17.8)	(-35.4, 17.8)	0.000*
24	-7.6 (23.1)	(-37.6, 50.8)		-11.4 (17.1)	(-34.8, 21.8)	
48	-12.3 (26.0)	(-46.7, 55.7)		-30.1 (12.8)	(-60.7, -17.0)	
72	-14.8 (26.3)	(-54.2, 51.2)		-23.5 (15.0)	(-44.3, 5.4)	

Table 10. General Linear Model ANOVA results for percent change in the average rate of RMS

Treatment Knee					Control Knee				
VL	**Coef**	**95% CI**	**T-Value**	**P-Value**	**VL**	**Coef**	**95% CI**	**T-Value**	**P-Value**
Constant	-0.1525	(-0.2067, -0.0984)	-5.73	0.000*	Constant	-0.1655	(-0.2206, -0.1453)	-9.88	0.000*
Duration					Duration				
0	0.0956	(0.0019, 0.1894)	2.08	0.046*	24	0.1030	(0.0496, 0.1802)	3.58	0.001*
24	0.0028	(-0.0909, 0.0966)	0.06	0.952	48	0.0301	(-0.035, 0.1270)	1.92	0.063
48	-0.0598	(-0.1535, 0.0340)	-1.30	0.204	72	-0.0840	(-0.1745, -0.0440)	-3.40	0.031*
72	-0.0387	(-0.1325, 0.0550)	-0.84	0.407	96	-0.0491	(-0.1327, -0.0021)	-2.10	0.043*
VM	**Coef**	**95% CI**	**T-Value**	**P-Value**	**VM**	**Coef**	**95% CI**	**T-Value**	**P-Value**
Constant	-0.2018	(-0.2517, -0.1518)	-8.22	0.000*	Constant	-0.1828	(-0.2707, -0.0949)	-13.17	0.000*
Duration					Duration				
0	0.0950	(0.0084, 0.1815)	2.23	0.032*	24	0.1788	(0.0265, 0.3311)	1.95	0.060
24	-0.0008	(-0.0873, 0.0858)	-0.02	0.986	48	-0.0073	(-0.1595, 0.1450)	1.13	0.268
48	-0.0477	(-0.1343, 0.0388)	-1.12	0.270	72	-0.0863	(-0.2386, 0.0660)	-1.60	0.120
72	-0.0465	(-0.1331, 0.0400)	-1.09	0.282	96	-0.0852	(-0.2375, 0.0670)	-1.56	0.128
RF	**Coef**	**95% CI**	**T-Value**	**P-Value**	**RF**	**Coef**	**95% CI**	**T-Value**	**P-Value**
Constant	-0.0788	(-0.1293, -0.0283)	-3.18	0.003*	Constant	-0.1757	(-0.2146, -0.1367)	-9.19	0.001*

Duration					Duration				
0	0.1102	(0.0228, 0.1977)	2.56	0.015*	24	0.0357	(0.0538, 0.1926)	3.62	0.001*
24	0.0027	(-0.0848, 0.0901)	0.06	0.950	48	0.1446	(-0.0052, 0.1283)	1.88	0.070
48	-0.0441	(-0.1315, 0.0434)	-1.03	0.313	72	-0.1258	(-0.1920, -0.0584)	-3.82	0.001*
72	-0.0688	(-0.1563, 0.0186)	-1.60	0.119	96	-0.0596	(-0.1264, 0.0072)	-1.82	0.079

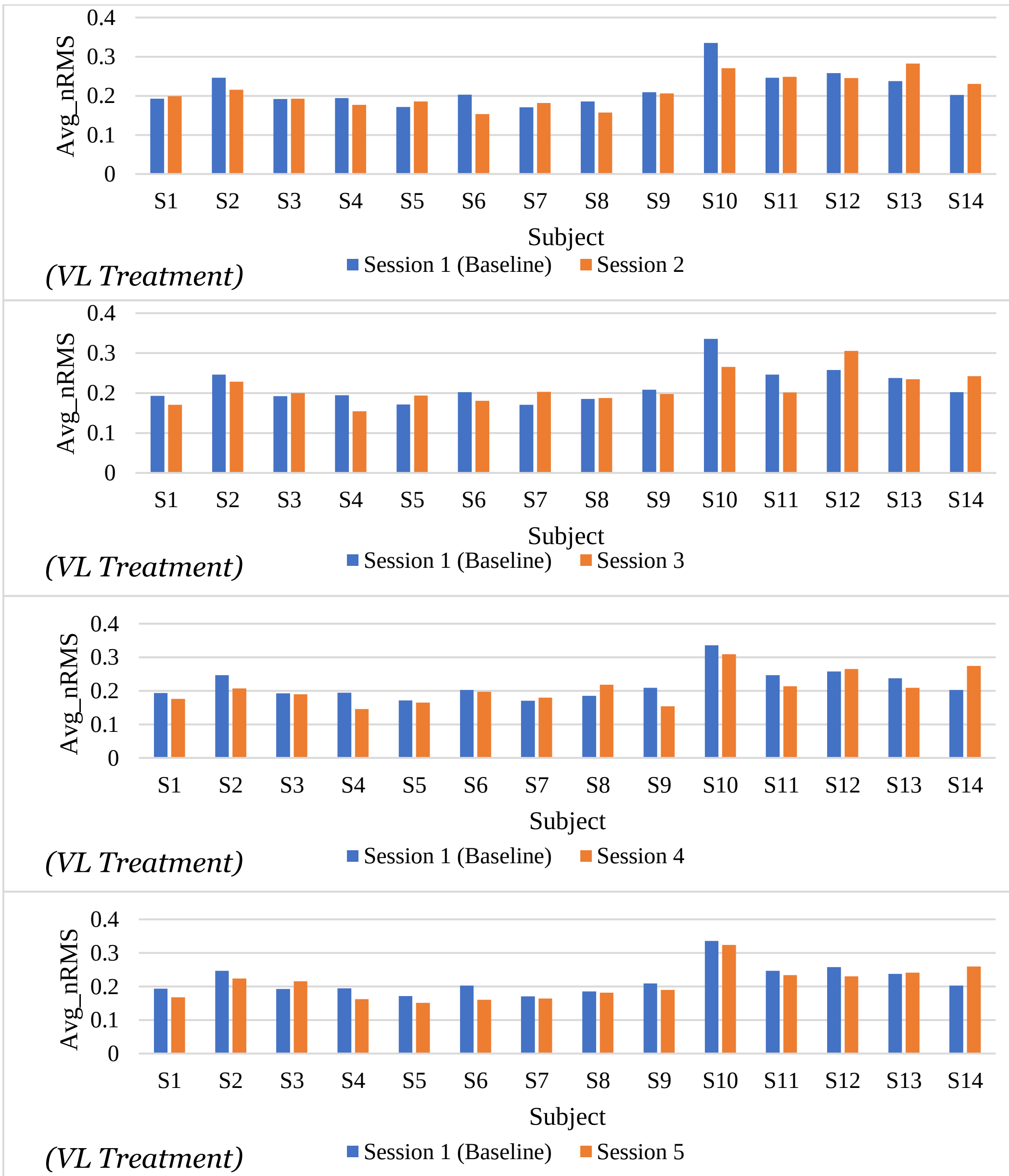


Figure 39. Average percent change in RMS of treatment knee across 5 sessions

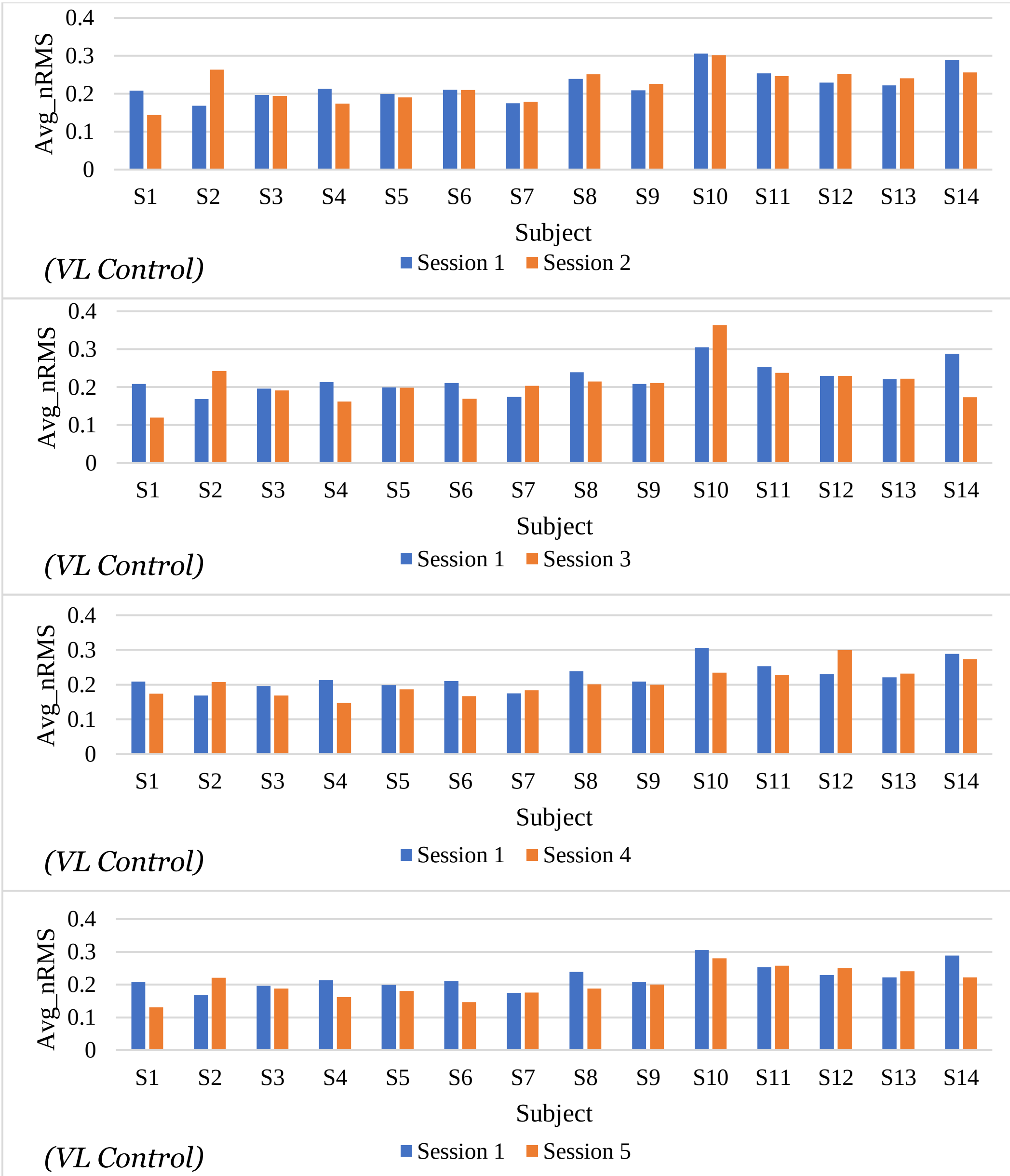


Figure 40. Percent change in RMS of control knee across 5 sessions

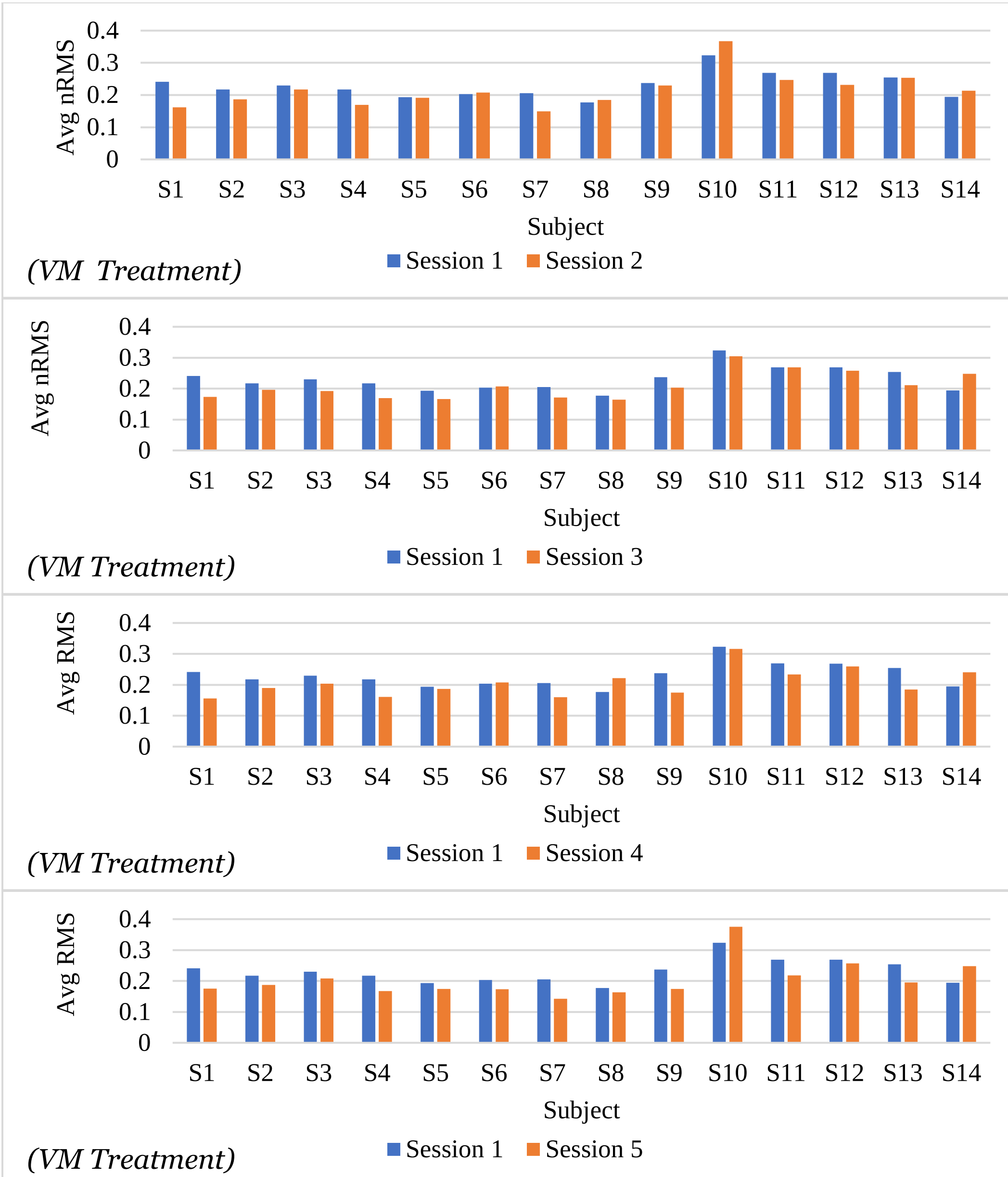


Figure 41. Percent change in RMS of treatment knee across 5 sessions

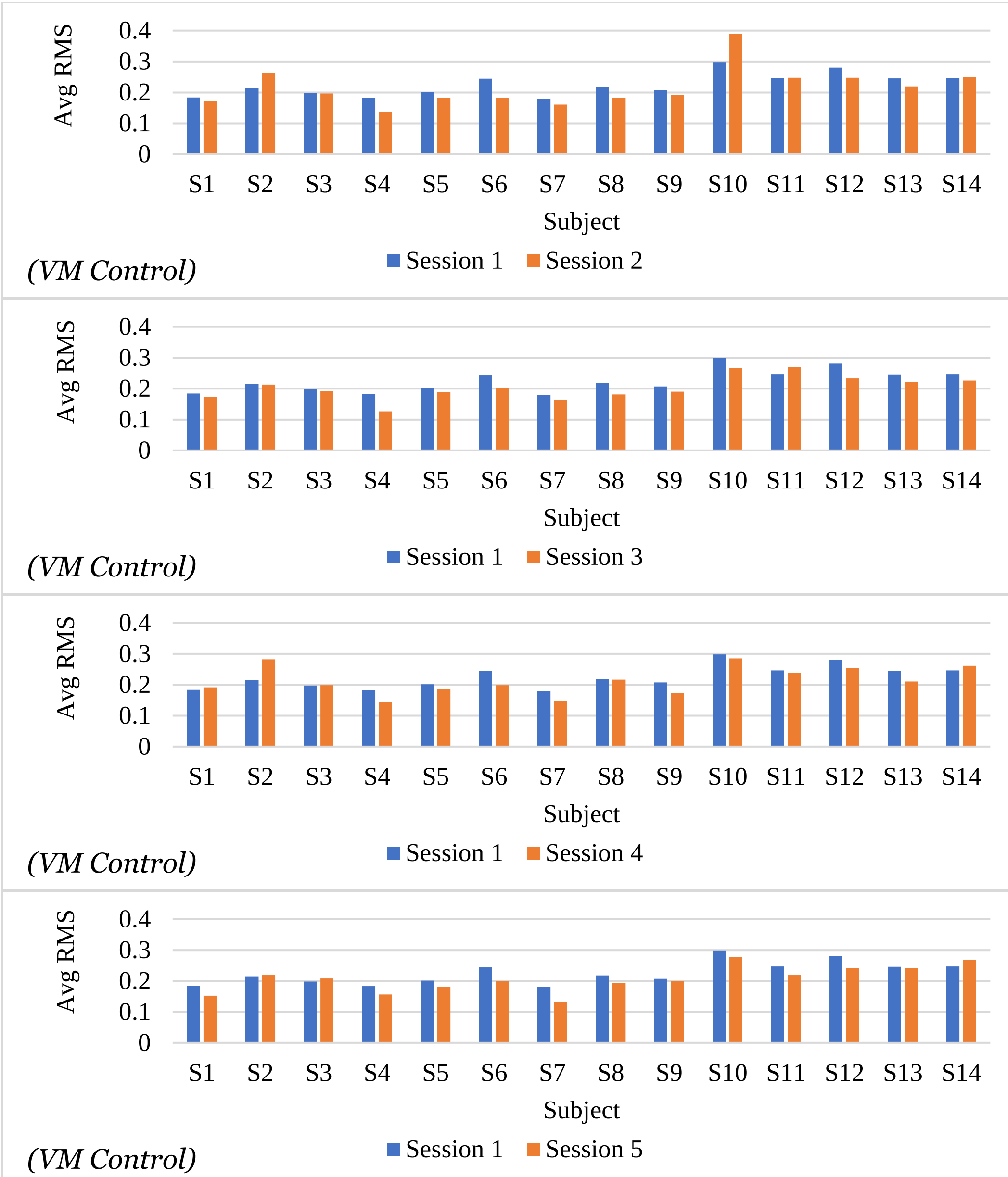


Figure 42. Percent change in RMS of VM of control knee across 5 sessions

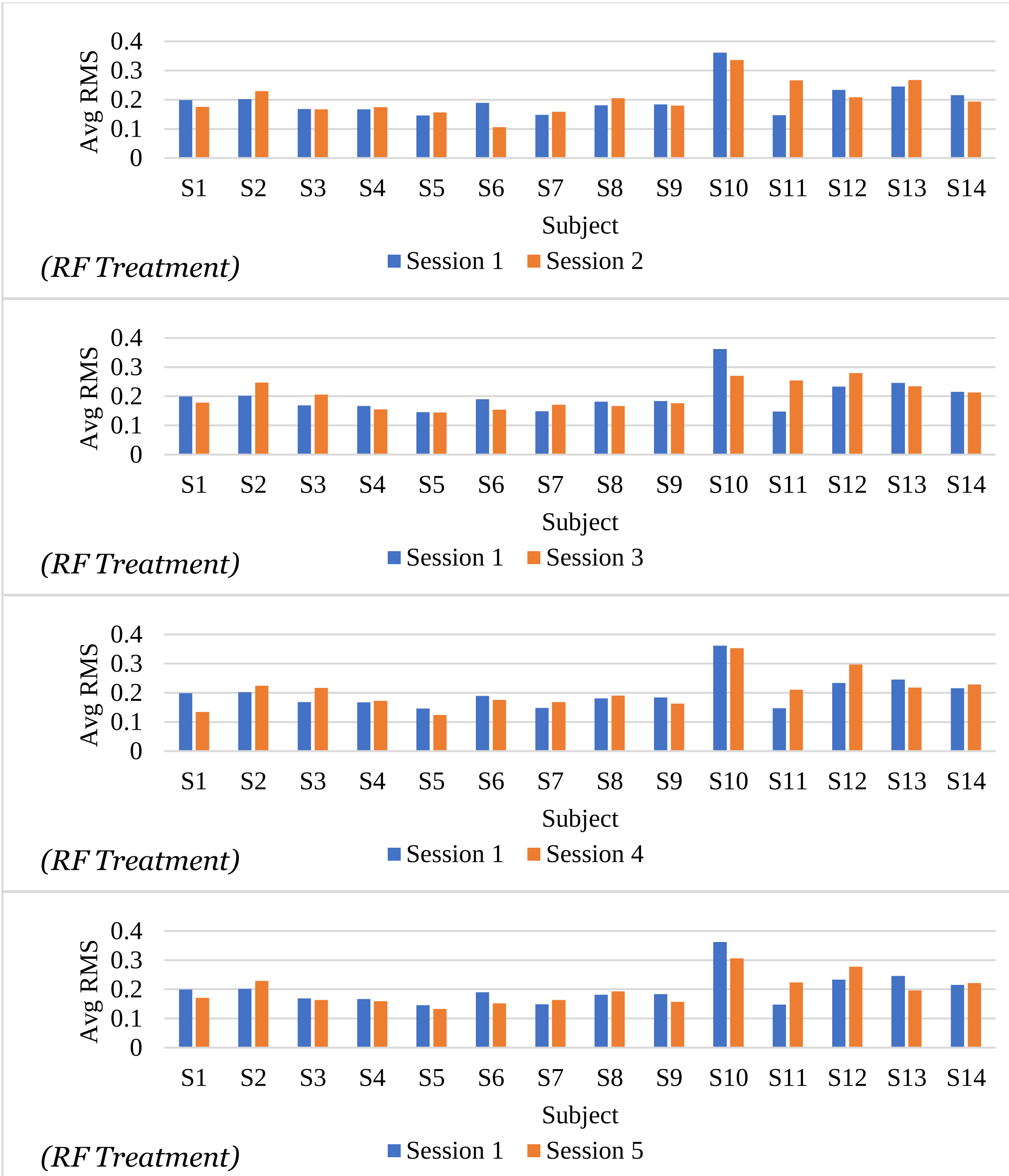


Figure 43. Percent change in RMS of RF of treatment knee across 5 sessions

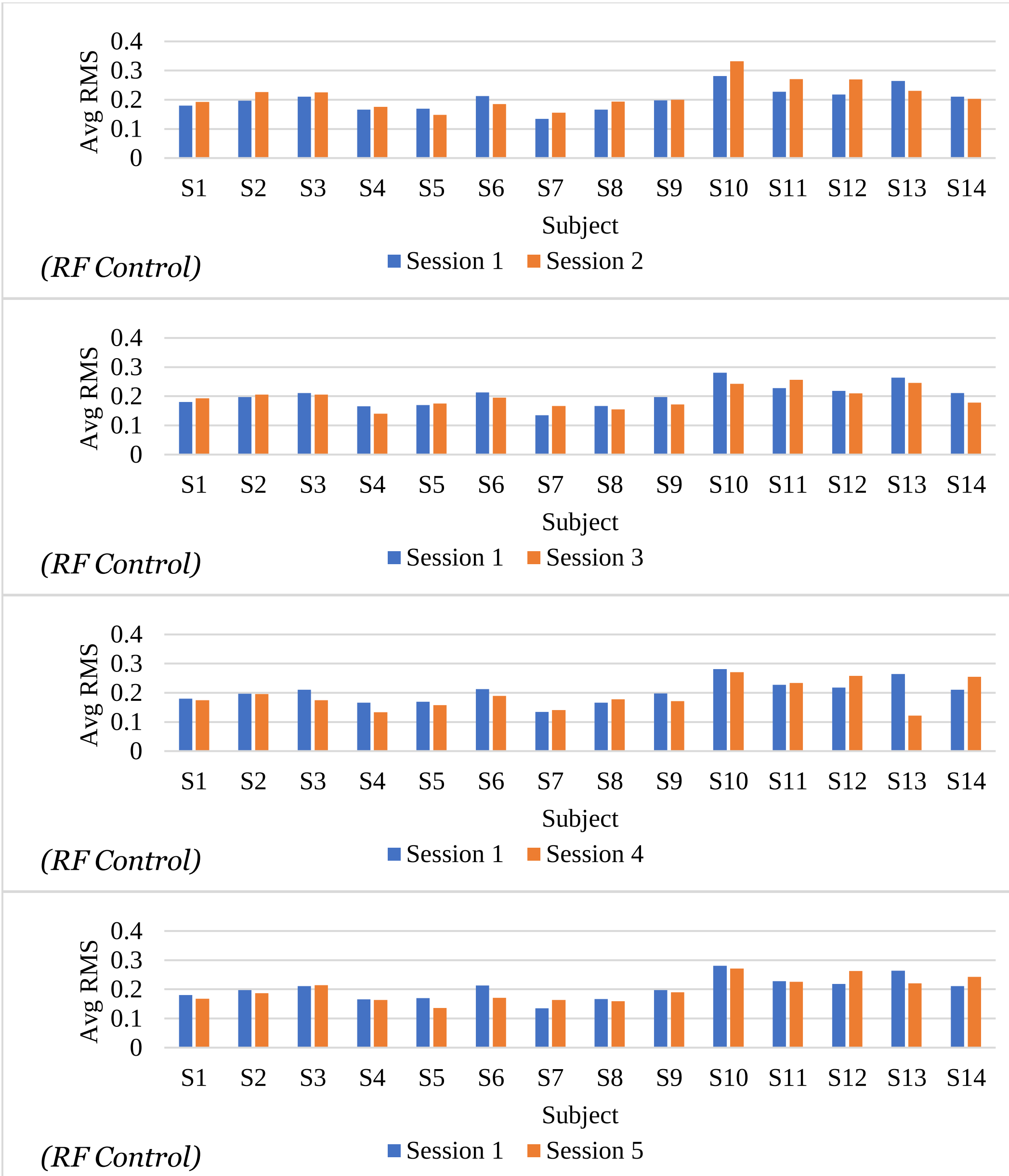
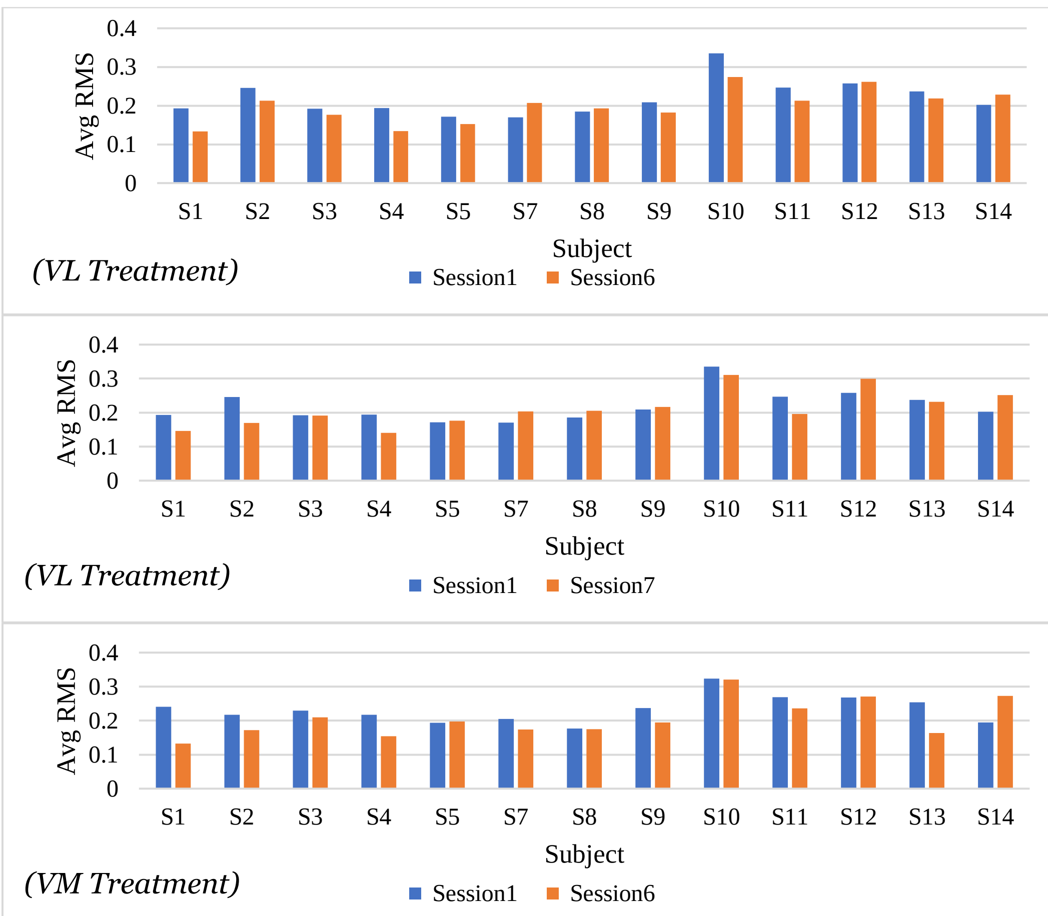


Figure 44. Percent change in RMS of RF of control knee across 5 sessions

The results from application duration have shown us that the effect of KT application was not substantial on delaying the muscle fatigue but the changes were due to the learning effect. The post-application results provide more evidence that the increase in muscle endurance was because of learning rather than KT application. A continued decrease in average RMS was observed (24 hours and 48 hours) after the removal of KT in sessions 6 and 7 in the treatment knee. There were 10 subjects who had a decrease in rate of change in RMS of all quadriceps muscles (subjects 1, 2, 3, 4, 5, 7, 8, 9, 10, 11, 13) in session 6 (Figure 45). In session 7, there were still 9 subjects who had decrease in rate of RMS change in all muscles for the treatment knee. This result is the consistent with the results of the control knee. The control knee continued to have a decrease in rate of change in RMS, with 10 subjects who had decreased rate of RMS for all muscles in the control knee in session 6 (subjects 1, 3, 4, 5, 7, 8, 9, 10, 11, 13). The number of subjects who had decrease in rate of RMS of all quad muscles rose to 11 subjects for session 7 (subjects 1, 2, 3, 4, 5, 7, 8, 9, 10, 11, 13).



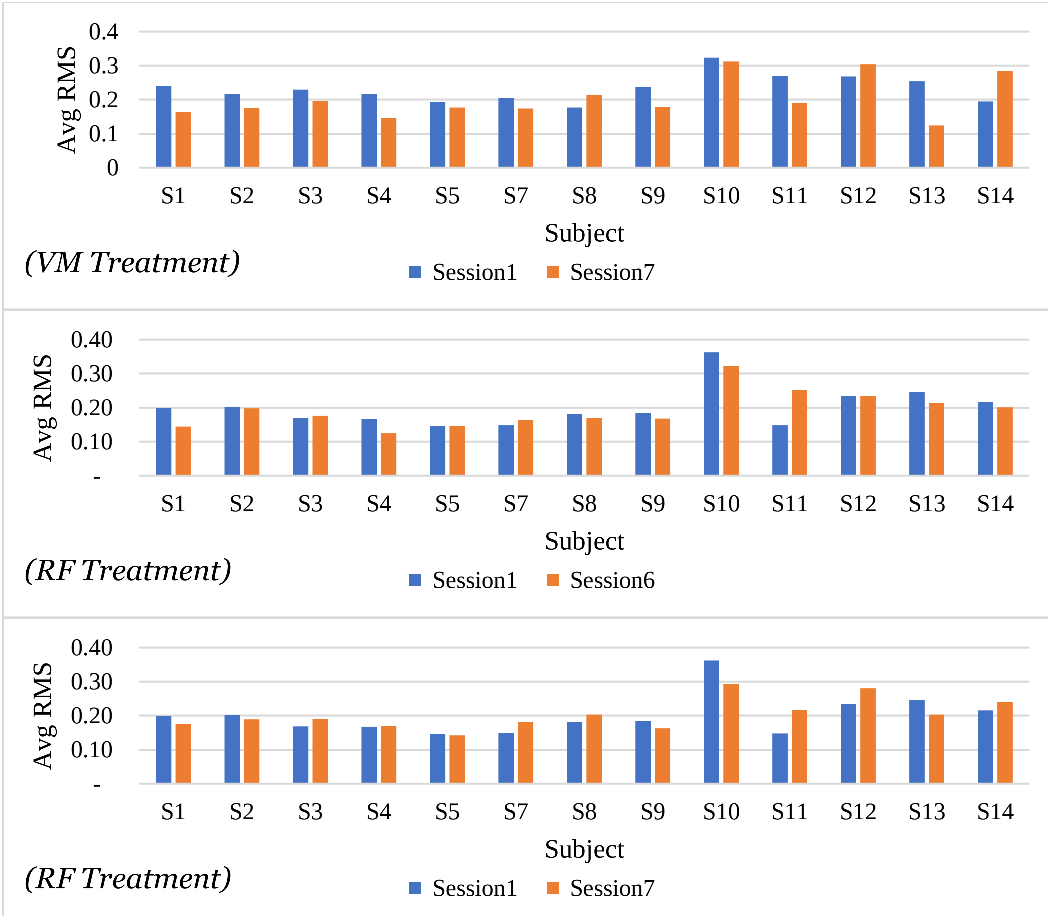


Figure 45. Average RMS of treatment knee across 5 sessions

3.2.4.2 Electromyography Median Frequency (EMG MDF)

Percent change in rate of change in MDF exhibited a large difference between subjects. For the VL, the percent change of rate in MDF ranged between -51.9% and 42.0%. For VM rate, of change in MDF ranged from -56.6% to 41.6%. The range of percent change in rate of RF ranged between -51.1% and 51.8% (Table 11). A large difference in the rate of RMS between subjects was also observed in the control knee. The percent change of rate in MDF ranged from -44.8% to 19.0% for VL, -39.1% to 15.9% for VM, and -38.0% to 36.2% for RF.

The number of subjects who had a decrease in rate gradually reduced across sessions. In the treatment knee, six subjects 3, 4, 5, 8, 9, 10) had decreased rate in MDF in session 2, and the number of subjects grew to 7 (3, 4, 5, 7, 8, 9, 13) in session 3. In session 4, the number of subjects who had decreased rate in MDF reached 8 subjects 1, 2, 3, 5, 7, 8, 9, 10).

Nevertheless, in the control knee, the number of subjects who had a decrease in rate of MDF also increased across sessions. Five subjects 3, 4, 6, 9, 11 had decreased rate in MDF in session 2, which increased to 7 subjects (3, 5, 8, 9, 10, 11, 13) in session 3. In session 4 the number of subjects who had decreased rate in MDF reached 11 subjects 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 13. This similarity in the percent change in rate of MDF between the treatment and control knees suggests the effect of learning.

Table 11. The average values and ranges of percent change in rate of change in MDF in the treatment knee and control knee in each session across 4 application durations

Duration of KT application (hrs.)	VL (Treatment)			VL (Control)		
	Mean (SD)	(Min, Max)	p-value	Mean (SD)	(Min, Max)	p-value
0	0.4 (22.9)	(-29.6, 41.8)	0.439	-12.0 (10.6)	(-27.4, 10.6)	0.145
24	-5.7 (24.1)	(-33.8, 42.0)		-11.6 (14.2)	(-31.1, 19.0)	
48	-10.0 (19.8)	(-38.7, 24.6)		-22.8 (12.4)	(-38.7, 1.0)	
72	-8.9 (24.2)	(-51.9, 41.3)		-19.2 (18.7)	(-44.8, 2.4)	
Duration of KT application (hrs.)	VM (Treatment)			VM (Control)		
	Mean (SD) %	(Min, Max) %	p-value	Mean (SD) %	(Min, Max) %	p-value
0	-1.3 (18.1)	(-37.2, 32.4)	0.257	-6.9 (11.4)	(-25.7, 15.2)	0.147
24	-8.8 (22.8)	(-34.4, 41.6)		-10.3 (16.3)	(-36.6, 11.6)	
48	-11.5 (21.4)	(-47.5, 33.4)		-20.2 (11.8)	(-39.1, -2.8)	
72	-11.3 (31.6)	(-56.6, 27.4)		-17.1 (17.6)	(-38.3, 15.9)	
Duration of KT application (hrs.)	RF (Treatment)			RF (Control)		
	Mean (SD) %	(Min, Max) %	*p*-value	Mean (SD) %	(Min, Max) %	*p*-value
0	1.4 (21.6)	(-31.7, 39.6)	0.422	-11.8 (12.2)	(-35.4, 17.8)	0.319
24	-6.6 (22.1)	(-32.6, 51.8)		-10.6 (15.5)	(-34.8, 21.8)	

48	-7.6 (26.0)	(-43.8, 51.3)		-22.0 (9.7)	(-35.3, -4.6)	
72	-8.8 (24.1)	(-51.1, 29.7)		-14.8 (21.5)	(-38.0, 36.2)	

In addition to the rate of change in MDF, the average MDF for each subject in all sessions was calculated in both the treatment knee and the control knee (Figures 46, 47, 48). In the treatment knee, an increase in average MDF was observed in the session 3. An increase in average MDF was observed in 8 out of 14 subjects (1, 2, 3, 6, 7, 10, 11, 12) for VL, 7 out of 14 subjects 1, 3, 6, 7, 10, 11, 12 for VM, and 11 subjects for RF (subjects 1, 2, 3, 4, 5, 6, 9, 11, 12, 13, 14). Meanwhile, an increase in average MDF was also observed in control knee, indicating the learning effect. The control knee had an increase in average MDF in 6 out of 14 subjects 1, 2, 3, 5, 11, 12 for VL (Figure 47), in 5 subjects 1, 4, 6, 7, 12 for VM (Figures 47) and in 6 subjects 1, 4, 6, 8, 11, 12 for RF (Figures 48).

In sessions 4 and 5, there was a continuous increase in the number of subjects who had increased average MDF in the treatment knee (Figures 46, 48, 50). The number of subjects who had increased average MDF in VL of grew from 8 subjects in session 4 (subjects 1, 3, 4, 6, 7, 10, 11, 13) to 10 subjects 1, 2, 3, 4, 5, 6, 7, 9, 11, 13 in session 5. The number of subjects who had increased average MDF in VM from 7 subjects 1, 4, 6, 7, 10, 11, 13 in session 4 to 8 subjects 1, 4, 6, 7, 9, 11, 13, 14 in session 5. In RF, the number of subjects also grew from 10 subjects (2, 3, 4, 5, 6, 7, 9, 11, 12, 13) to 11 subjects 1, 2, 3, 4, 5, 6, 7, 9, 11, 12, 14.

According to the result of general linear ANOVA, there was no significant effect of KT application duration on the change in average MDF of VL, VM, and RF in the treatment knee (p = 0.647, p = 0.748, p = 0.927, respectively). There was also no substantial effect on decreasing the rate of change in MDF in the treatment knee (Table

11). In the control knee, no significant change in average MDF of VL, VM, and RF (p = 0.640, p = 0.880, p = 0.059, respectively) was observed. There was also no significant decrease in the rate of change in MDF of VL, VM, and RF (Table 11).

Figure 46. *Results of average MDF in VL of the treatment knee from each subject across 5 sessions*

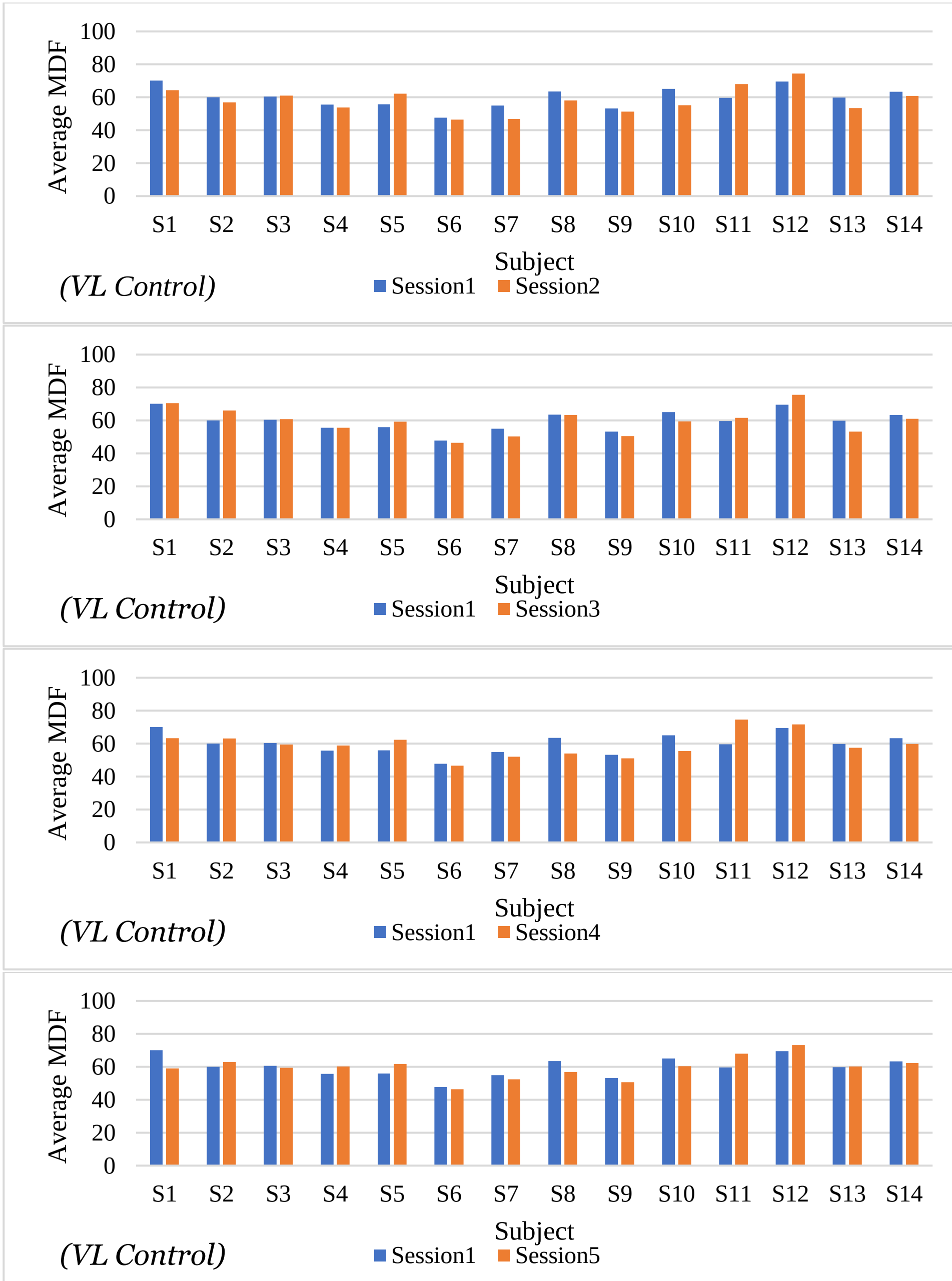


Figure 47. Results of the percent change in MDF of the treatment knee across 5 sessions

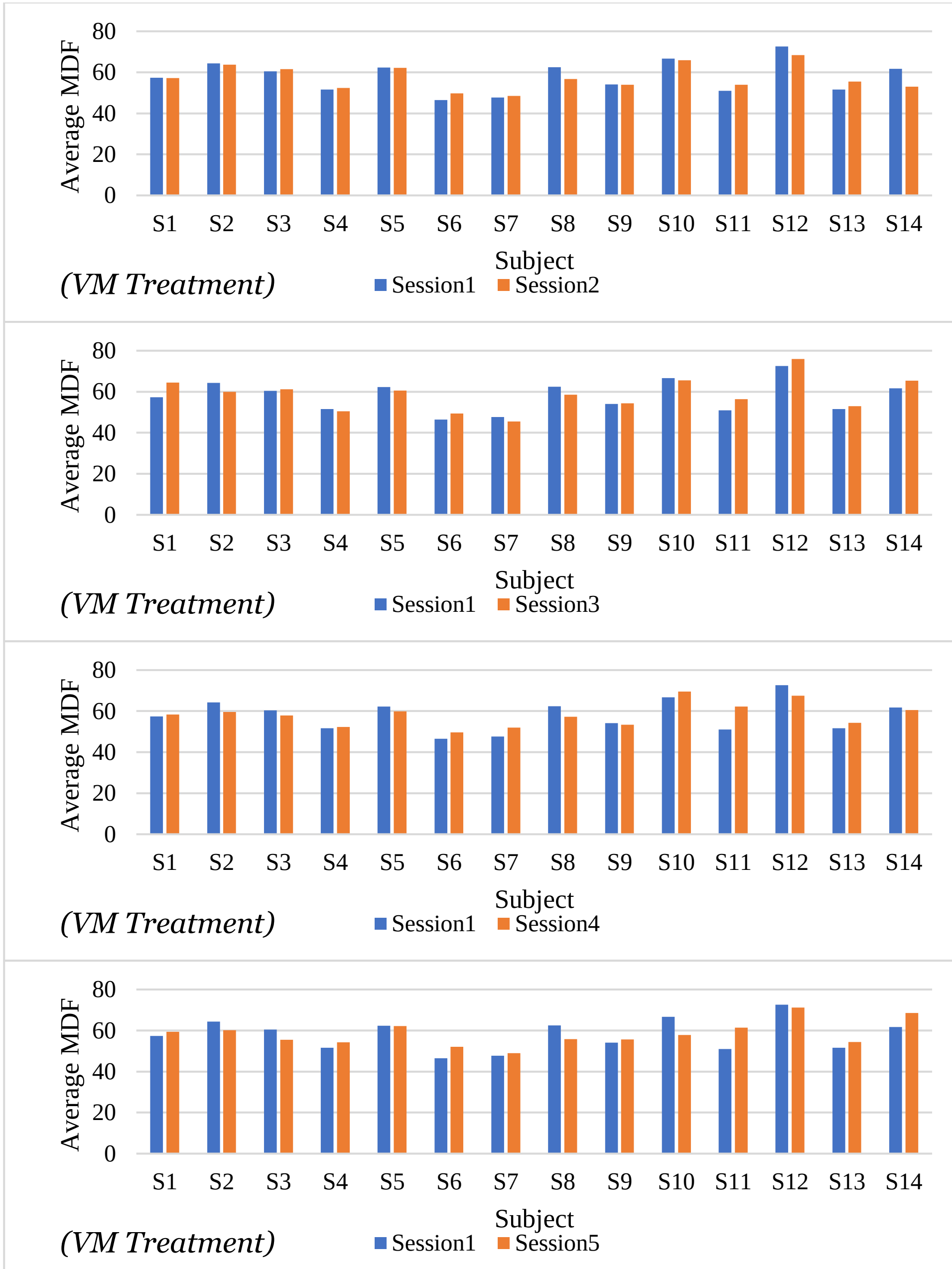


Figure 48. Results of the average MDF in VM of the treatment knee for each subject across 5 sessions

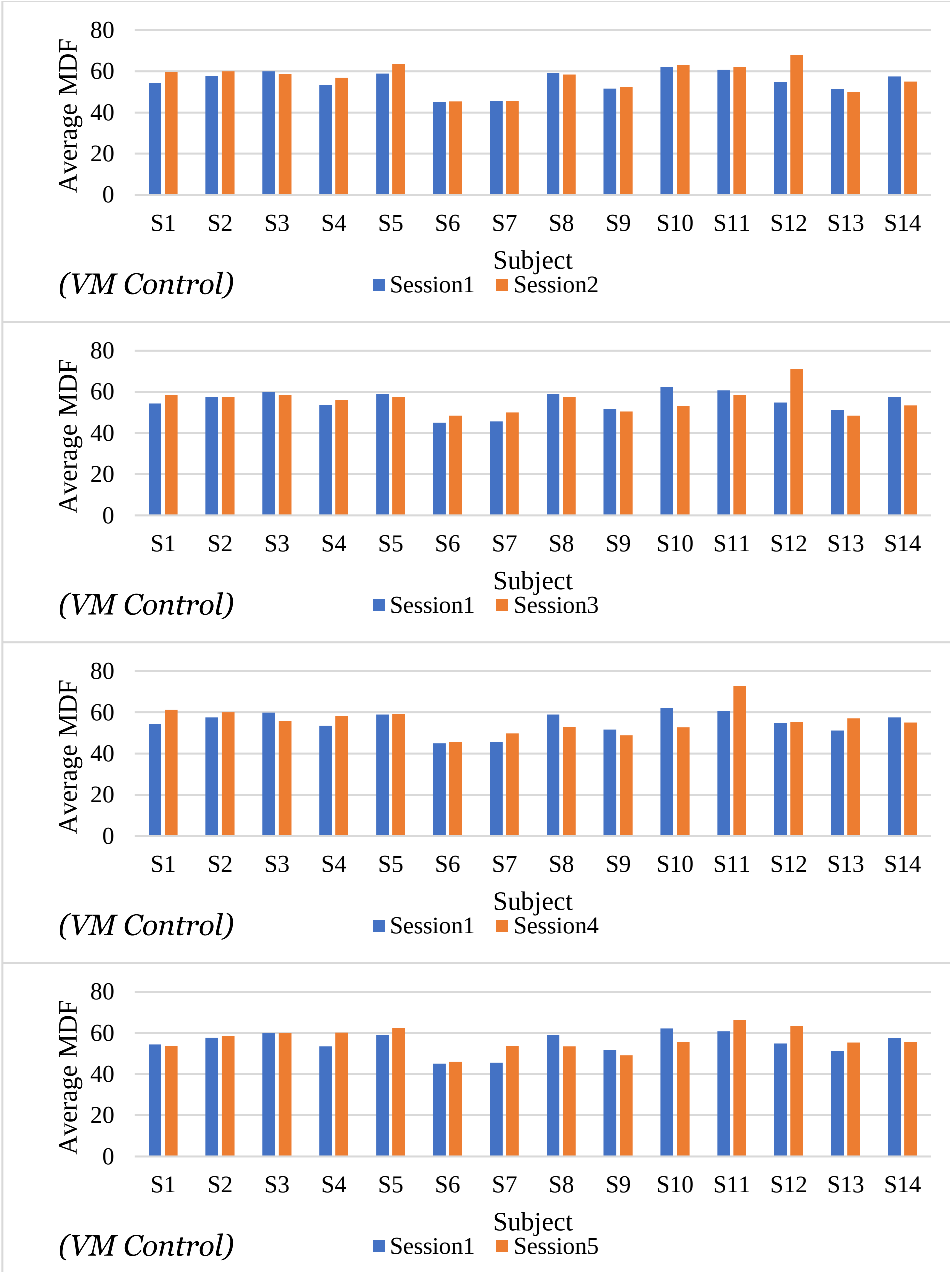


Figure 49. Results of average MDF in VM of the control knee from each subject across 5 sessions

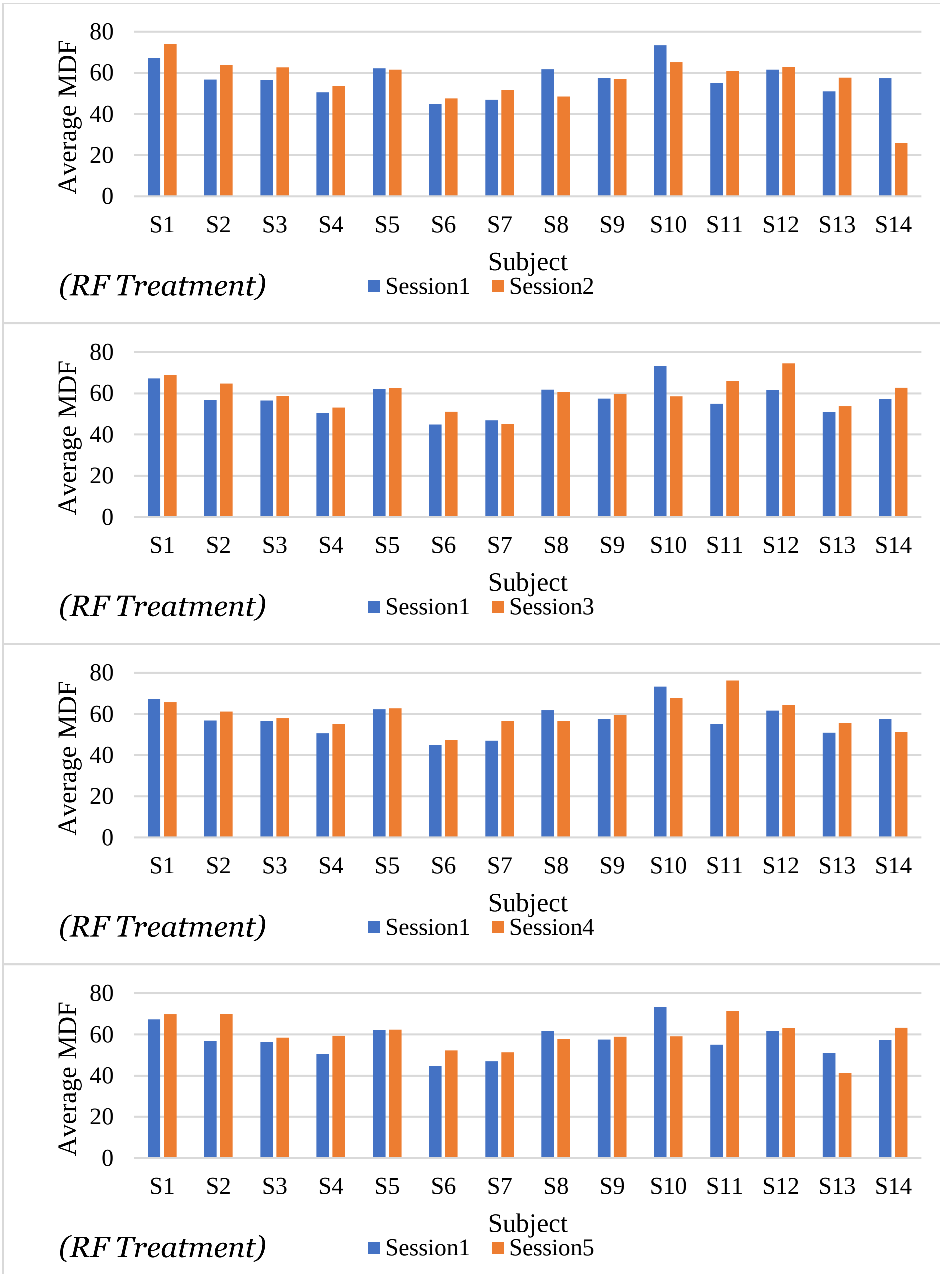


Figure 50 Results of average MDF in RF of treatment knee from each subject across 5 sessions

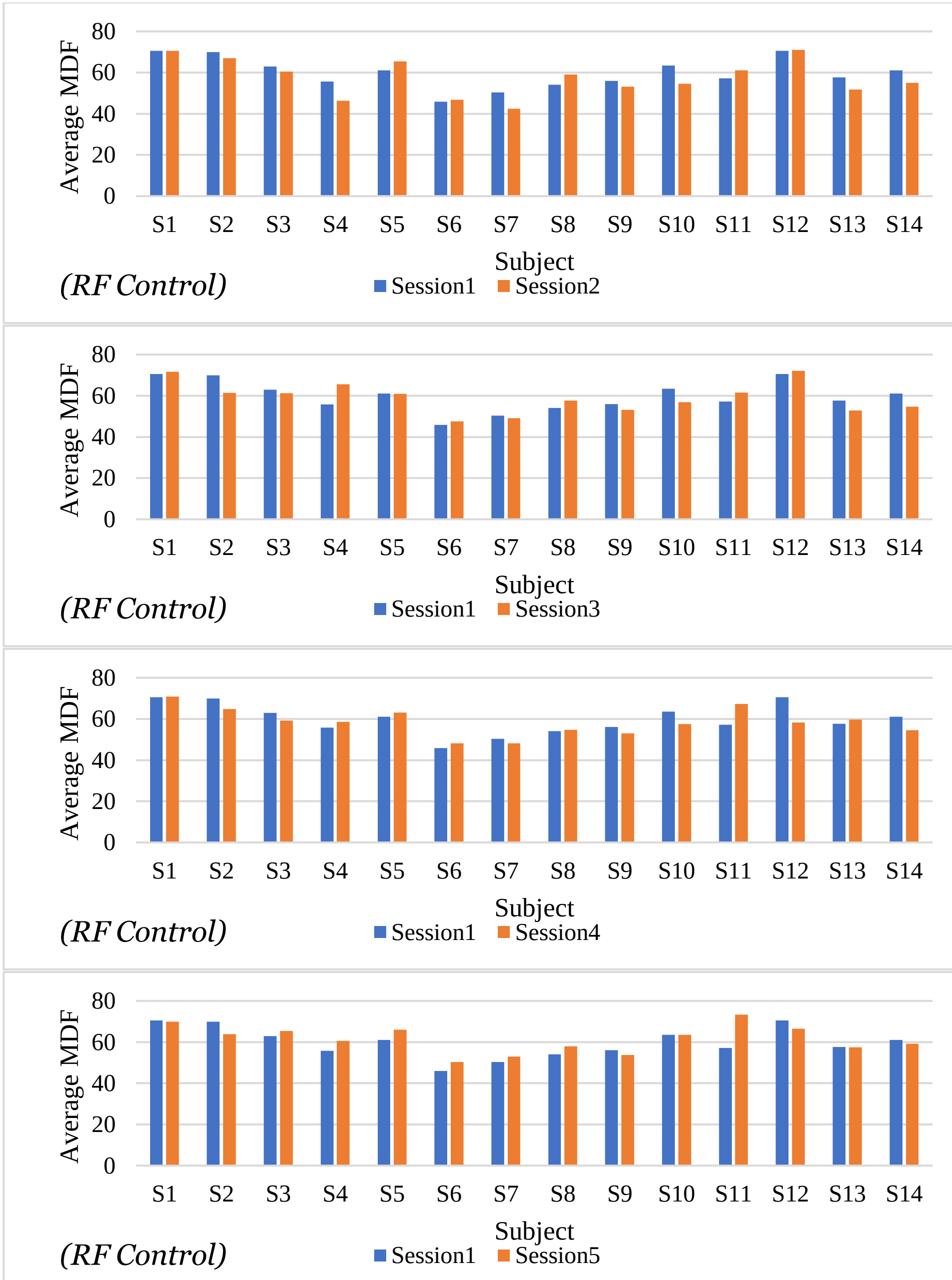
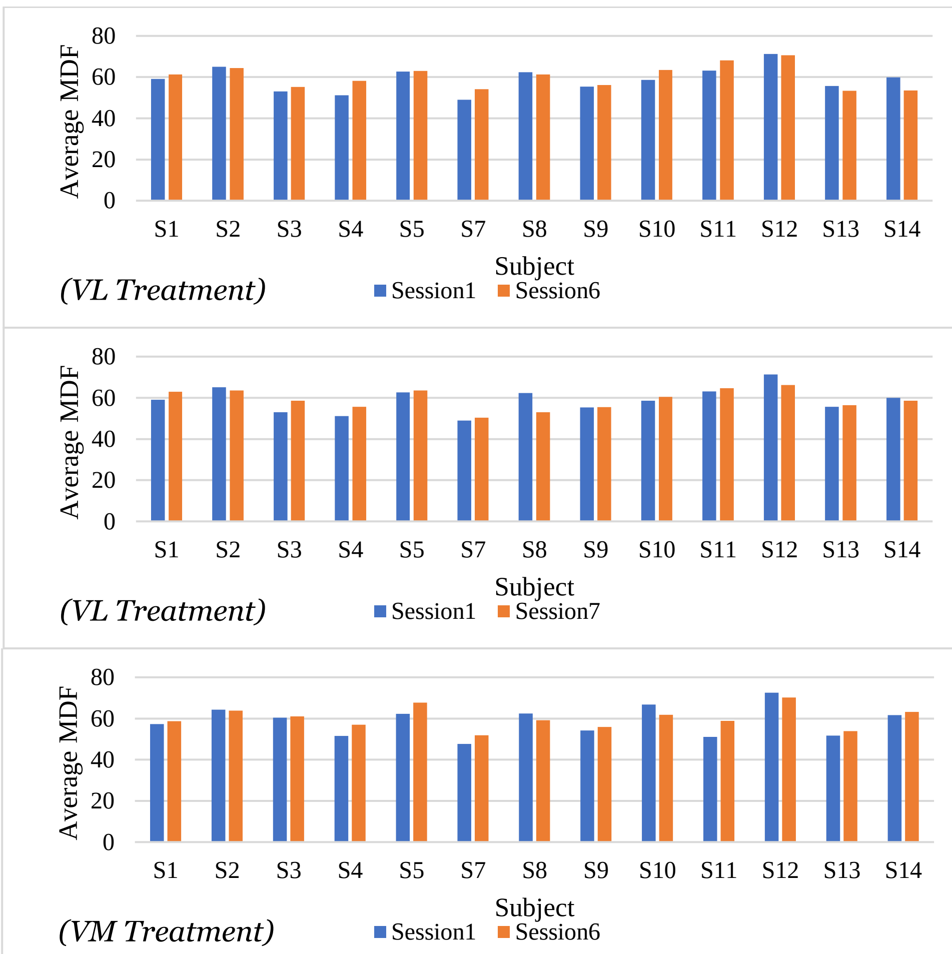


Figure 51. Results of average MDF in RF of control knee from each subject across 5 sessions

There was no substantial effect on decreasing the rate of change in MDF in treatment knee and control knee during application of KT and continued increases in average MDF during post-application in both knees would be evidence for a learning effect (Figure 52). Consistent with the result of RMS, more subjects had increased average MDF during sessions 6 and 7 in both knees. There were 11 subjects who continued to increase their average MDF in the treatment knee in sessions 6 and 7 (subjects 1, 2, 3, 4, 5, 7, 9, 10, 11, 13, 14). Similar to the treatment knee, 10 subjects had increased average MDF in the control knee for session 7, and 11 subjects who had decreased rate of change in MDF (subjects 1, 2, 3, 4, 5, 7, 8, 9, 10, 11, 13, 14).



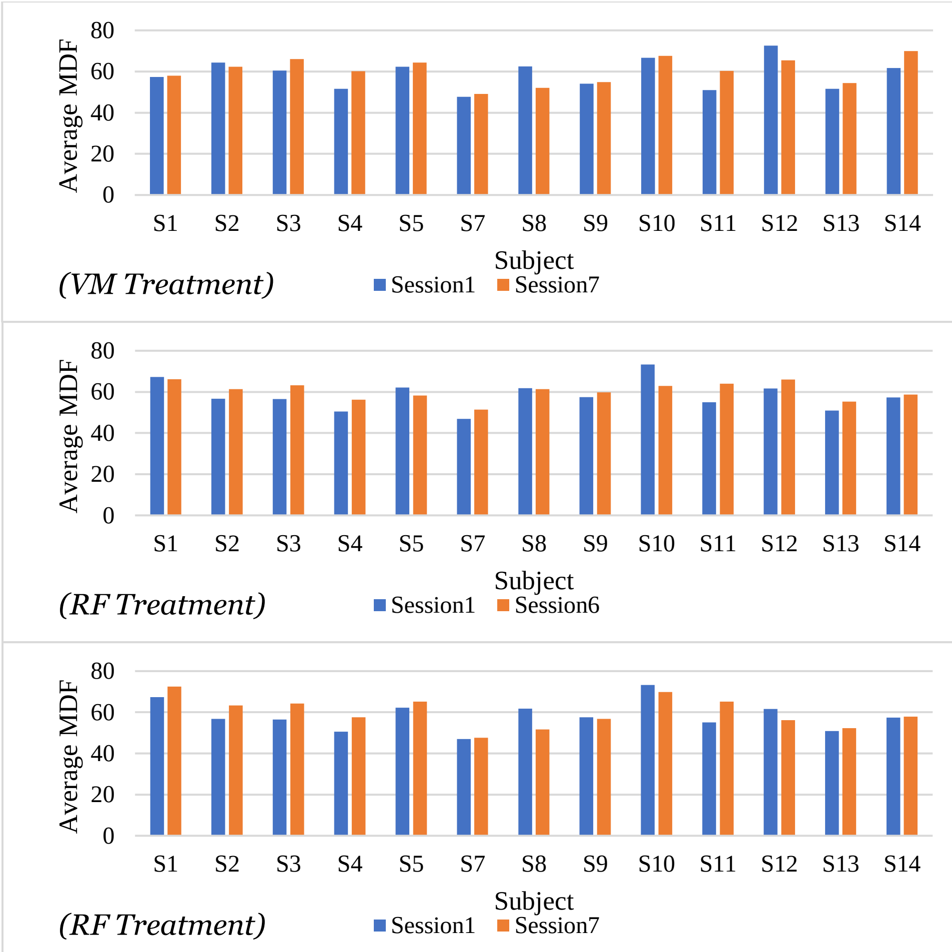


Figure 52. Average MDF in sessions 6 and 7

3.2.5 Change in Cycle Rates

There was a slight variation in the cycle rate between subjects. Cycle rate ranged between 0.51 and 1.30 repetitions per second in the treatment knee, and between 0.48 and 1.24 repetitions per second in the control knee (Figures 53 & 54). The cycle rate changes ranged between a 30.06% decrease to a 35.42% increase in treatment knee, while the percent change in the control knee ranged from a 26.82% decrease to an increase of 26.43% (Table 14).

However, there was an observed increase in cycle rate in the treatment knee with duration within subjects. Seven subjects1, 3, 5, 7, 8, 9, 11 had minimal increases in the cycle rate. Three subjects 10, 12 and 14 had large increases in cycle rate over the duration of the sessions. Four subjects 2, 5, 6, 13 had no increases in cycle rates. Subject 4 had noticeably slower cycle rates and higher TTF over the application durations compared to the baseline session. The result of general linear ANOVA shows that there was no significant difference with respect to the cycle rate for the treatment knee (p = 0.225).

In the control knee, five subjects 1, 3, 6, 7, 8 slightly accelerated their cycle rate across test sessions though most control knee TTF had an increasing trend. Subject 12 had an increasing rate of cycle which resulted in the observed decrease in TTF and number of cycles over the duration. Eight subjects 2, 4, 5, 9, 10, 11, 13, 14 had minimal changes in their speed. There was no substantial difference in cycle rate between sessions for the control knees (p = 0.562).

Table 12. Results of percent change in rate of cycles for each 24-hour increment of duration

	Treatment knee			Control knee		
Duration(hrs)	Mean (SD) %	(Min, Max) %	*p*-value	Mean (SD) %	(Min, Max) %	*p*-value
0(Immediate)	2.31 (11.47)	(-30.06, 22.42)	0.225	-2.07 (10.12)	(-26.82, 15.91)	0.562
24	3.75 (12.06)	(-26.33, 26.10)		1.61 (5.44)	(-9.64, 10.09)	
48	6.39 (16.38)	(-29.04, 35.42)		3.97 (8.31)	(-6.56, 26.43)	
72	6.13 (15.14)	(-26.73, 31.34)		6.87 (10.01)	(-7.69, 26.20)	

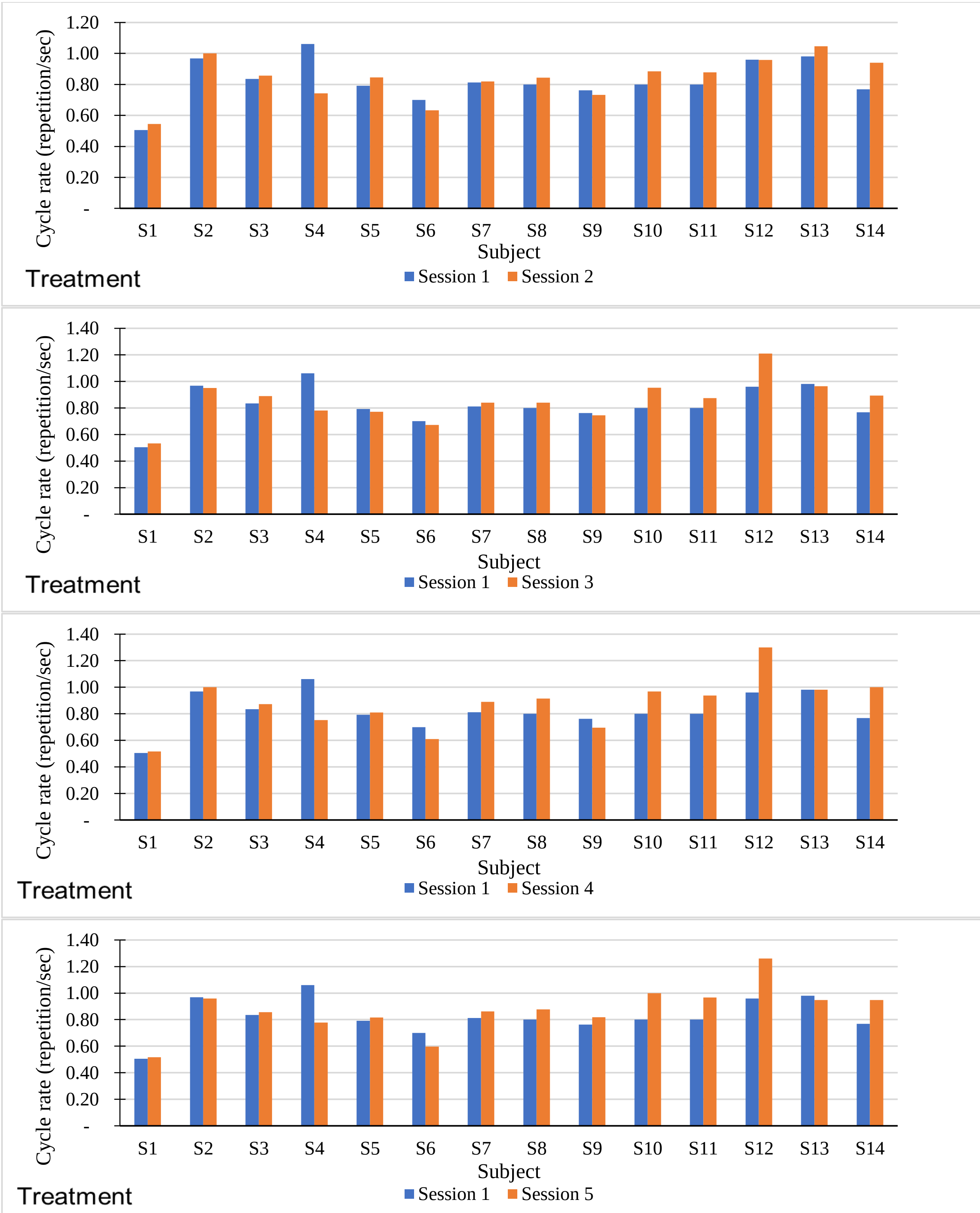


Figure 53. Cycle rate in the treatment across 5 sessions

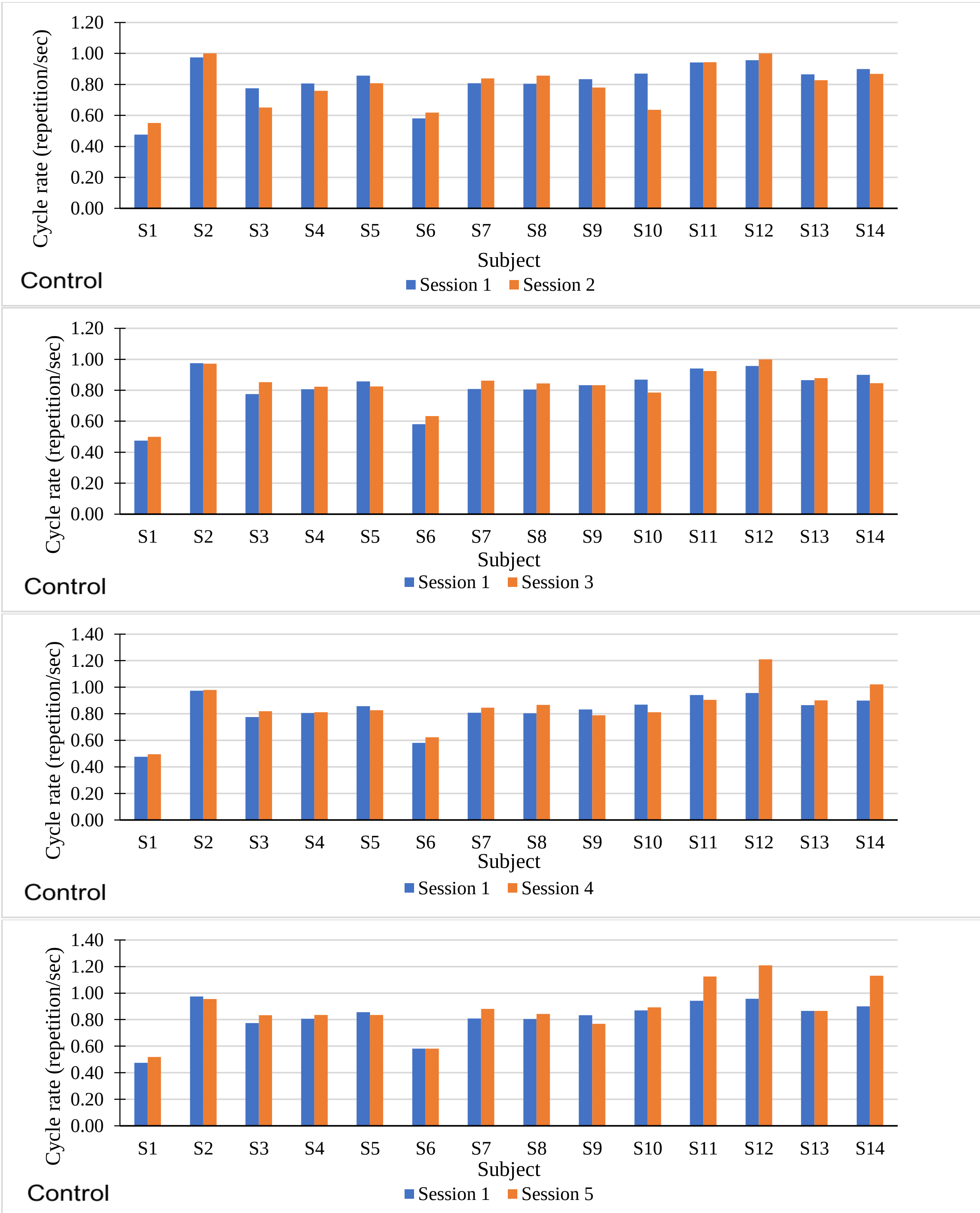
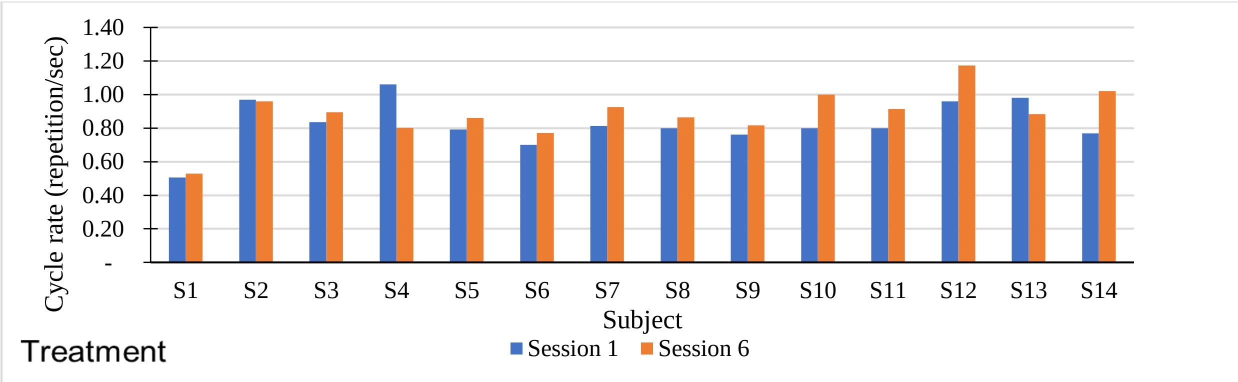


Figure 54. cycle rate in the control knee across 5 sessions

For the treatment knee, eleven subjects had higher cycle rates in session 6 compared to the baseline sessions, however, increases in TTF and number of cycles were found in most subjects. The treatment knee had an increase of 0.06 repetitions/sec (±0.12) on average in sessions 6. Particularly, subjects 10, 12, and 14 had large increases in cycle rate, while decreased TTF and number of cycles were observed in subjects 12 and 14. Three subjects 2, 4, 13 had decreases in the cycle rate in session 6. Subject 4 was noted to have a noticeably decreased cycle rate, with dramatic increases in TTF and the number of cycles.

In session 7, cycle rates increased in ten out of fourteen subjects, while increases in TTF and the number of cycles in the treatment knee were found for most of subjects. On average, an increase of 0.07 repetitions/sec (±0.16) was observed in sessions 7. Subjects 10, 12, and 14 had higher increases in cycle rate compared to session 6 which resulted in a decrease in TTF and the number of cycles. Three subjects 2, 4, 13 had decreased cycle rates in session 7. A distinct reduced cycle rate compared to session 6 was noted in subject 4 who had a major increase in TTF.



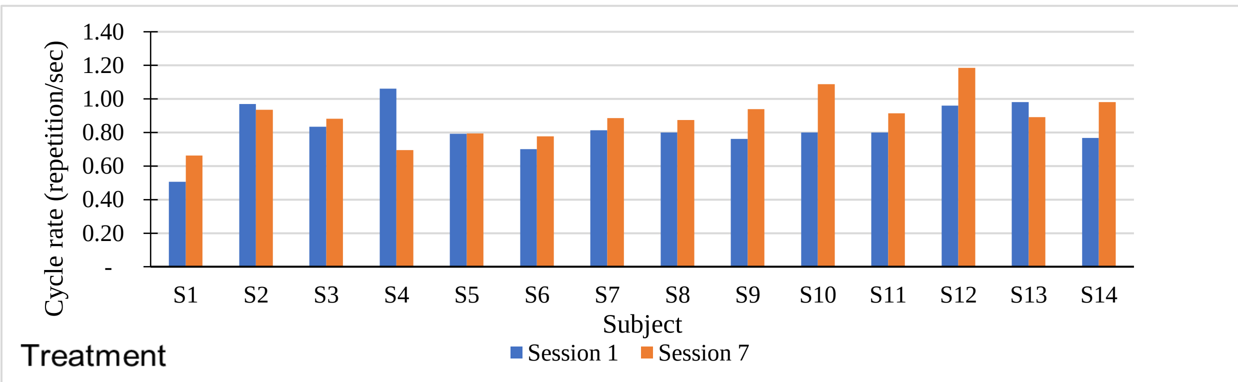


Figure 55. Cycle rates in sessions 1, 6, and 7

For the control knee, nine subjects 1, 3, 6, 7, 8, 9, 12, 13, 14 increased their cycle rate in session 6 compared to the baseline session. Subject 12 had an increase of 0.28 repetitions per second when both TTF and the number of cycles dropped. Five subjects (2, 4, 5, 11, 12) had minimal decreases in cycle rates. Session 6 had an average increase of 0.05 repetitions per second (±0.08) in cycle rate. In session 7, an increase in TTF and accelerated speed were observed in the control knee for all subjects except subjects 12 and 14. The increase in cycle rate was 0.05 (±0.07) on average.

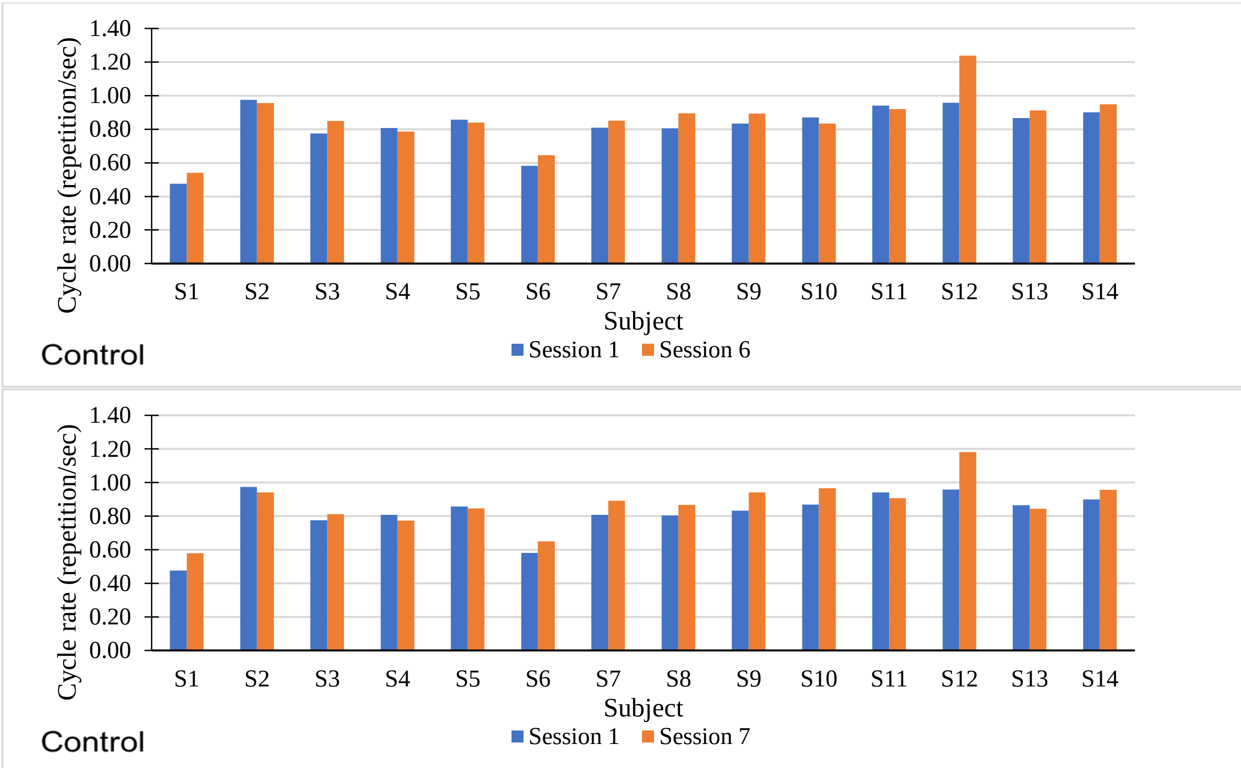


Figure 56. cycle rates of the control knee in sessions 6 and 7

Chapter 4 Discussion

The goal of this study was to evaluate the effect of KT application and application duration on joint endurance during isotonic fatiguing knee flexion/extension exercise. Time to fatigue, number of cycles, muscle activity, and muscle oxygenation were all collected across seven test sessions with and without KT application. Based on the results of this study, KT did not have benefits on joint endurance during knee extension/flexion fatiguing exercise.

The three evaluated hypotheses were:

(1) KT application will enhance joint endurance. The effect of KT application was examined in the treatment knee by making a comparison between Pre-Application (session 1) and Application (session 2).

(2) Longer duration of KT application will further enhance joint endurance. The effect of application duration can be observed in the treatment knee by evaluating the percent change between Pre-Application (session 1) and Application Durations (sessions 2, 3, 4, 5).

(3) Prolonged exercise can enhance joint endurance regardless of KT. The learning effect across duration was studied by observing the percent change from session 1 to sessions 2, 3, 4, 5 in the control knee.

4.1 Hypothesis I: KT Application

KT application was hypothesized to enhance the endurance of knee joint. For time to fatigue, the result showed that there was no significant difference in TTF between pre-application (session 1) and application (session 2) in the treatment knee (75.7 ± 72.1, 74.0 ± 68.6, p = 0.779). The increase in TTF was associated with a decrease in cycle rate for some subjects. In terms of number of cycles, KT application also failed to show significant change in endurance from session 1 to 2 within subject (70.8 ± 59.6, 73.4 ± 56.8, p = 0.346).

This result was also supported by the physiological data findings: muscle activity and muscle oxygenation. There was no delay in TTM in either VL (p = 0.867) or VM (p = 0.546). No significant decrease in rate of drop in muscle oxygenation was observed from session 1 to 2 in VL (0.45 ± 0.3, 0.46.0 ± 0.3, respectively; p = 0.788) or in VM (0.21 ± 0.14, 0.20 ± 0.16, respectively; p = 0.821).

Regarding muscle activity, KT application also did not result in an enhancement of endurance in terms of decrease in amplitude of muscle activity from session 1 to 2 in VL, VM, or RF (p = 0.148, p = 0.051, p = 0.695, respectively). The frequency of muscle EMG activity was observed to have no difference from session 1 to 2 in VL, VM, and RF (p = 0.368, p = 0.710, p = 0.175, respectively).

The change in muscle oxygenation especially revealed muscle synergy and muscle coactivation. There was an observed delay in time to minimum muscle oxygenation in VM in subjects, but this resulted from the coactivation of muscles VL and RF. Time to minimum rSO_2 in VM was observed to be increased while time to minimum rSO_2 in VL was decreased. Furthermore, VL and RF were the dominant muscles to perform the knee flexion/extension which was seen in the muscle activity. The muscle activity also revealed muscle synergy and muscle coactivation. While there was a decrease in amplitude of EMG for VM, an increase in amplitude of muscle activity for VL and RF was observed. The VL and RF co-activated to assist VM and prolong the endurance time.

These findings are consistent with previous studies with respect to physical performance (Cavaleri et al., 2018;Reneker et al., 2018; de Jesus et al., 2017; Lee et al., 2017; Serra et al., 2015; Poon et al., 2014; Vercelli, 2012; Fu et al., 2008). Cavaleri et al. (2018) reported that KT applied to the quadricep muscles and knee joint did not have an effect on extensor strength and single leg hop test performance for healthy subjects. Reneker et al. (2018) reported that evidence supporting KT application for enhancing sport perforance is limited. There is no effect of KT applicaion on joint endurance and funtional performance for healthy subjects. Jesus et al.(2017) reported that KT applied to the quadricep muscles and knee joint has no effect on extensor strength and single leg hop test performance for healthy subjects. Lee et al. (2017) examined the change in muscle endurance and self-perceived fatigue after immediate KT application for quadricep muscles and knee joints during the half-squat test, and found that KT application did not diminish the effect of fatigue or enhance the quadricep muscle endurance. Serra et al. (2015) found that KT did not affect the force-related measures and assessed the difference after immediate KT application compared with 3M Micropore - paper tape application, during maximal isometric knee extension. Poon et al., (2014) also showed that no significant differences in maximum jump or peak jump power between KT taping and sham taping. Vercelli (2012) exhibited no significant effect in the maximal quadriceps' strength after immediate application of KT or sham KT. Serrao et al. (2016) measured the difference in amplitude of muscle activity in quadriceps of healthy subjects between without-tape, KT, and placebo tape during barbell back squat, and they did not find any changes in amplitude of muscle activity for quadriceps after KT application. Halski (2015) compared muscle activities of quadriceps between KT application and sham tape (3M tape) application on knee joint during resting and knee extension and observed no changes in amplitude of muscle activity in healthy subjects after KT application. Fu et al. (2008) compared without-taping and immediate-taping and revealed that there was no significant difference in muscle power after KT taping. KT on the thigh neither decreased nor increased muscle strength in healthy athletes.

4.2 Hypothesis II: Duration of KT Application

KT application durations, up to 72 hours, were hypothesized to enhance the endurance of the knee joint. For time to fatigue, the results showed that TTF was increased by 6.77% on average after 24 hours of KT application, and there was a 11.79% percent increase in TTF in session 4 after 48-hr application compared to the baseline session. An increase in 12.55% on average was found after 72-hr KT application. Although there was an increase on average across sessions, the result showed no significant changes in TTF after KT application was applied for 0, 24, 48, 72 hours (session 2, 3, 4, and 5, respectively) for the treatment knee ($p = 0.711$). The increase in TTF was only observed in certain subjects instead of the majority of subjects in this study.

Regarding the number of cycles, there was no significant percent increases across KT application durations ($p = 0.381$). The percent increase in number of cycles on average was 8.31% (±21.73%) in session 3, and an average percent increase of 17.03% (±27.78%) was observed in session 4. An increase of 16.77% (±40.71%) was observed in session 5. The number of cycles had a gradual increase on average, but those increases were also only observed in certain subjects instead of the majority of subjects.

The physiological data results of muscle activity and muscle oxygenation also showed that there were no significant changes in TTM rSO_2 across application durations either in VL ($p = 0.778$) or VM ($p = 0.234$). There were also no decreases in rate of drop in muscle oxygenation from pre-application to application sessions either in VL ($p = 0.786$) or VM ($p = 0.611$). However, there was a decrease in amplitude of muscle activity across sessions, although the decreases were not statistically significant for VL, VM, RF ($p = 0.191$, $p = 0.156$, $p = 0.073$, respectively). The frequency of muscle activity was also observed to be slightly increased across sessions, but the improvement was also insignificant for VL, VM, and RF (p = 0.439, p = 0.257, p = 0.422, respectively).

These results are consistent with a previous study in which Stedge (2012) examined the differences in endurance duration between pre-application, 24 hours after, and 72 hours after KT application, and the result showed no substantial difference in measured endurance ratio.

The observed delay in fatigue of muscles in the treatment knee across sessions was due to the learning effect, where subjects learned to change their posture and strategy to delay fatigue in their extensors. During the post-KT application sessions, where KT was removed for 24 and 48 hours, subjects' time endurance still had an increasing trend. Furthermore, most subjects had their peak values in TTF and number of cycles during post-application sessions instead of application sessions.

For subjects who had a decrease in amplitude and an increase in frequency of EMG for treatment knee, they had observed postural change across sessions based on video recording. Posture change may explain the decrease in some muscle activity by trading it off to other muscle group.

Several previous studies showed evidence of hamstring muscle coactivation during knee joint extension. Aagaard et al. (2000) showed that bicep femoris corresponded to about 30% of its agonist quadriceps during quadricep contraction. Amiridis et al. (1996) and Kellis et al. (1996) presented that coactivation of muscles was significantly higher in sedentary subjects than in highly skilled subjects during knee extension.

Overall, the KT application and application duration were not seen to enhance muscle endurance and function. The reason is the mechanism of muscle contraction cannot improved by outward application. Muscle contraction happens inside the muscle fibers. Muscle contraction is a repetitive series of chemical fusion and catabolism inside the muscle fibers (Metzler, 2003). The mechanism of muscle contraction was associated to calcium ions binding to troponin (Wakabayashi, 2015), and this begins with adenosine triphosphate hydrolyzed to adenosine triphoate and phosphate group (Dunn et al., 2020). Myosin heads extend and bind to actin forming cross-bridges, and it pulls the actin filament toward the M line and shorten the sarcomere (Smith et al., 2007; Cooper et al., 2000). KT application is on the outward side of the skin, so it is difficult for such an application to assist in muscle contraction. Taping over the skin outwardly doesn't involve or help the known muscle activation mechanism. Based on the present study and the support of previous studies, KT application and application duration cannot facilitate the mechanism of muscle contraction. Some reseachers propose that KT promotes muscle endurance by improving proprioceptive feedback, which is based on the concept that propriceptive feedback has the potential to enhance muscle performance (Dean, 2013). However, the evidence for this concept is limited. Muscle propriocetion, stability, and performance all rely on muscle endurance (Klika, 2011; Ju et al., 2010; Ribeiro et al., 2007; Voight et al., 1996), and KT application has been shown to have no clinical effect on knee joint endurance in this study.

4.3 Hypothesis III: Learning Effect

The learning effect was hypothesized to delay the muscle fatigue during isotonic knee flexion/extension exercise in control knee across 5 sessions. Although the percent increase in TTF was not statistically significant (*p*= 0.187), the result showed that control knee had a gradual percent increase in TTF and number of cycles which were larger than the percent increase in the treatment knee in sessions 3, 4, and 5.

In the control knee, TTF was increased by 2.94% on average in session 2 and by 7.67% in session 3 compared to the baseline session. An increase in TTF by 19.37% on average was found in session 4 and of 18.00% in session 5. The statistical insignificance may due to the increase in cycle rate across sessions. Nevertheless, the number of cycles had significant percent increases across sessions ($p = 0.023$). The percent increase in number of cycles on average was 1.38% (±22.76%) in session 2 and 9.07% (±22.32%) in session 3. An increase of 22.30% (±25.33%) was observed in session 4, and there was an increase of 23.87% (±30.75%) in session 5. The gradual increase in endurance was observed in most of the subjects across sessions.

This result was not consistent with a previous study from Pliner (2015), because the researcher did not look at the control knee. Pliner presented a pilot study that KT application durations could delay time to fatigue during isotonic knee flexion/extension over 7 days. However, there were limitations of this previous study including a lack of a control and the limited pilot sample size of 4 subjects.

Alt et al, (2014) and Wang et al. (2017) presented that familiarization across time increases time endurance and learning effect can be observed in a control knee. Jesus et al. (2015) also observed the learning effect in their study. They examined the changes in performance of single hop test of distance with different conditions: control (no KT), KT application, and sham application on knee joints and quads for 5 days. An increase in performance was found in all taping conditions, indicating the learning effect of subjects.

Another mechanism for how subjects delayed their endurance time for the control knee across sessions is motor learning (Campbell-Kyureghyan et al., 2020). Motor learning is a relatively permanent gain for motor skills. Our whole body identifies outward stimuli, and our brains send electrical impulse to proper related muscles after learning from past experience in memory and decision making (Wang & Chen, 2014). The pattern of measured learning motor is subject's increased performance curve across trials of muscle function (Schmidt, Lee, Winstein, Wulf, & Zelaznik, 2018). Brech et al. (2011) and Rodrigues-da-Silva et al. (2017) found that motor learning improved subjects' endurance time on a dynamometer without any treatment in 2 sessions.

4.4 Limitations of This Study

There are four limitations to this study: (1) placebo effect was not examined; (2) KT was only applied on subjects' dominant leg in this research; (3) near-infrared spectroscopy and EMG sensors were applied on the quadricep muscles only in this research; and (4) only male subjects were recruited. The placebo effect was not examed as we did not apply sham tape on subjects' control knees. The placebo effect was observed in subjects who knew about KT. Subjects 3 and 4 who knew about KT tape before the test performed better with taping application during the test, while most of the subjects saw indifferent performance regardless of KT application. Many previous studies have indicated that even sham tape conditions made subjects perform better in muscle strength and performance compared to control conditions. KT was only applied on subjects' dominant leg in this research. The non-dominant leg was always set as the control knee. However, results of the treatment knee and control knee were not compared directly. Changes in parameters across sessions were calculated as percent change to normalize the differences. Pairwise comparison to the baseline values of the control knee and treatment knee saw no significant difference in baseline values between the two. Future studies should include the leg factor in the experiment. Near-infrared spectroscopy and EMG sensors were applied on the quadricep muscles only in this research due to the limitation of sensor placement. Assessing the hamstring muscles is needed in future studies of KT application.

Chapter 5 Conclusion

There are currently several studies examining KT and joint endurance in the literature. However, an extensive review, while showing a plethora of information, highlights a lack of reliable and consistent data. This study was designed to determine the effect of KT application duration on knee joint endurance in healthy subjects during a fatiguing isotonic knee extension/flexion exercise. The impact of KT application was evaluated through biomechanical analysis with and without KT application. Our research suggests:

1. KT application did not enhance knee joint endurance during isotonic knee flexion/extension exercise.
2. Application of KT did not delay muscle fatigue during knee isotonic flexion/extension fatiguing exercise
3. Longer duration of KT application, up to 72 hours, did not result in further significant higher endurance of the knee joint during isotonic fatiguing knee flexion/extension exercise.
4. Longer duration of KT application did not provide further significant delay in joint fatigue during knee isotonic flexion/extension fatiguing exercise.
5. Prolonged exercise delayed muscle fatigue during knee isotonic flexion/extension fatiguing exercise regardless of KT application.
6. Prolonged exercise enhanced knee joints endurance during isotonic fatiguing knee flexion/extension exercise regardless of KT application.

Our findings on healthy subjects indicate that there are no substantial differences in time to fatigue, the number of cycles, muscle oxygenation, and muscle activity of VL, VM, and RF after KT application, whether immediate or after some duration of application. Manufacturers claimed that KT can reduce muscle fatigue, enhance joint endurance, and improve blood flow. However, this study did not support these claims. Learning effect and postural changes can explain why joint endurance was enhanced regardless of KT application.

References

Aagaard, P., Simonsen, E., Andersen, J., Magnusson, S., Bojsen-Møller, F., & Dyhre-Poulsen, P. (2000). Antagonist muscle coactivation during isokinetic knee extension. *Scandinavian Journal of Medicine and Science in Sports*, 10(2), 58-67.

Abubaker, A. A., & Muaidi, Q. I. (2018). The effect of the inhibition technique of the kinesio taping on the triceps surae muscle after an isokinetic fatigue protocol. *MedCrave Online Journal of Orthopedics & Rheumatology*, 10(2), 384.

Agocs, S. (2020, April 11). How kinesiology tape really works. Retrieved from https://www.rocktape.com/2017/04/11/how-kinesiology-tape-really-works/

Aktas, G., & Baltaci, G. (2011). Does kinesiotaping increase knee muscles strength and functional performance? *Isokinetics and Exercise Science*, 19(3), 149-155.

Alt, T., Knicker, A. J., & Strüder, H. K. (2014). Factors influencing the reproducibility of isokinetic knee flexion and extension test findings. *Isokinetics and Exercise Science*, 22(4), 333-342.

Álvarez-Álvareza, S., Joséa, F. G.-M., & Rodríguez-Fernándeza, A. (2014). Effects of kinesio tape in low back muscle fatigue: randomized, controlled,doubled-blinded clinical trial on healthy subjects. *Journal of Back and Musculoskeletal Rehabilitation*, 27(2), 203-212.

Amiridis, I., Martin, A., Morlon, B., Martin, L., Cometti, G., Pousson, M., & van Hoecke, J. (1996). Co-activation and tension-regulating phenomena during isokinetic knee extension in sedentary and highly skilled humans. *European Journal of Applied Physiology and Occupational Physiology*, 73(1-2),149-156.

Barten, O. (2020, April 1). What we can do to keep runners going stronger longer. Retrieved from https://www.rocktape.com/2020/04/01/mulholland_runner/

Boushel, R., Langberg, H., Olesen, J., Gonzales-Alonzo, J., Bülow, J., & Kjær, M. (2001). Monitoring tissue oxygen availability with near infrared spectroscopy. *Scandinavian Journal of Medicine & Science in Sports*, *11*(4), 213-222.

Boushel, R., & Piantadosi, C. A. (2000). Near-infrared spectroscopy for monitoring muscle oxygenation. *Acta Physiologica Scandinavica*, 168(4), 615-622.

Brech, G. C., Ciolac, E. G., Secchi, L. L. B., Alonso, A. C., & Greve, J. M. D. A. (2011). The effects of motor learning on clinical isokinetic performance of postmenopausal women. *Maturitas*, 70(4), 379-382.

Brinkman, J. E., Toro, F., & Sharma, S. (2020). *Physiology, respiratory drive*. Treasure Island: StatPearls Publishing.

Campbell-Kyureghyan, N., Johnson, B., & Wu, A. (2020, July 12-14). Postural adjustment influence on endurance performance enhancements. In *The International Society of Electrophysiology and Kinesiology* [Symposium]. XXIII *International Society of Electrophysiology and Kinesiology* Virtual Congress, Tokyo, Japan.

Cavaleri, R., Thapa, T., Beckenkamp, P. R., & Chipchase, L. S. (2018). The influence of kinesiology tape colour on performance and corticomotor activity in healthy adults: a randomised crossover controlled trial. . *BMC Sports Science, Medicine and Rehabilitation*, 10(1), 1-8.

Choi, I. R., & Lee, J. H. (2019). The effect of the application direction of the kinesiology tape on the strength of fatigued quadriceps muscles in athletes. *Research in Sports Medicine*, 27(1), 1-10.

Choi, I. R., & Lee, J. H. (2019). Effects of the direction of kinesiology tape application on the delayed onset of quadriceps muscle fatigue in athletes. *Isokinetics and Exercise Science*, 27(3), 235-240.

Cifrek, M., Medved, V., Tonković, S., & Ostojić, S. (2009). Surface EMG based muscle fatigue evaluation in biomechanics. *Clinical Biomechanics*, 24(4), 327-340.

Cooper, G. M., & Hausman, R. E. (2000). *The cell: a molecular approach*. Washington DC: ASM Press.

Craighead, D. H., Shank, S. W., & Volz, K. M., & Alexander, L. M. (2017). Kinesiology tape modestly increases skin blood flow regardless of tape application. *Journal of Performance Health Research*, 1(1), 72-78.

da Silva, R. A., Vieira, E. R., Cabrera, M., Altimari, L. R., Aguiar, A. F., Nowotny, A. H., Carvalho, A. F. Oliveira, M. R. (2015). Back muscle fatigue of younger and older adults with and without chronic low back pain using two protocols: A case-control study. *Journal of Electromyography and Kinesiology*, 25(6), 928-936.

de Jesus, J. F., dos Santos Franco, Y. R., Nannini, S. B., Nakaoka, G. B., dos Reis, A. C., & Bryk, F. F. (2017). The effects of varied tensions of kinesiology taping on quadriceps strength and lower limb function. *International Journal of Sports Physical Therapy*, 12(1), 85.

De Luca, C. J., Gilmore, L. D., Kuznetsov, M., & Roy, S. H.(2010). Filtering the surface EMG signal: Movement artifact and baseline noise contamination. *Journal of biomechanics*, *43*(8), 1573-1579.

Dean, J. C. (2013). Proprioceptive feedback and preferred patterns of human movement. *Exercise and Sport Sciences Reviews*, 41(1), 36.

Dunn, J., & Grider, M. H. (2020). *Physiology, Adenosine Triphosphate (ATP)*. Treasure Island: StatPearls Publishing.

Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2009). Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods*, 41(4), 1149-1160.

Fu, T. C., Wong, A. M., Pei, Y. C., Wu, K. P., Chou, S. W., & Lin, Y. C. (2008). Effect of kinesio taping on muscle strength in athletes—a pilot study. *Journal of Science and Medicine in Sport*, 11(2), 198-201.

GonzáLez-Iglesias, J., Fernández-de-Las-Peñas, C., Cleland, J., Huijbregts, P., & Gutiérrez-Vega, M. D. R. (2009). Short-term effects of cervical kinesio taping on pain and cervical range of motion in patients with acute whiplash injury: a randomized clinical trial. *Journal of Orthopaedic and Sports Physical Therapy*, 39(7), 515-521.

Guilhem, G., Cornu, C., & Guével, A. (2011). Muscle architecture and EMG activity changes during isotonic and isokinetic eccentric exercises. *european journal of applied physiology and occupational physiologyinte Physiology*, 111(11), 2723-2733.

Gupta, R., & Agarwal, R. (2017). sEMG interface design for locomotion identification. *International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering*, 11(2), 117-226.

Halseth, T., McChesney, J. W., DeBeliso, M., Vaughn, R., & Lien, J. (2004). The effects of kinesio™ taping on proprioception at the ankle. *Journal of Sports Science and Medicine*, 3(1), 1.

Halski, T., Dymarek, R., Ptaszkowski, K., Słupska, L., Rajfur, K., Rajfur, J., & Taradaj, J. (2015). Kinesiology taping does not modify electromyographic activity or muscle flexibility of quadriceps femoris muscle: a randomized, placebo-controlled pilot study in healthy volleyball players. *Medical Science Monitor: International Medical Journal of Experimental and Clinical Research*, 22, 2232.

Hébert-Losier, K., Ngieng, S. Y., Martyn, B., Chow, L. T., & Jim, R. (2019). Physiological, kinematic, and electromyographic responses to kinesiologytype. *Journal of Electromyography and Kinesiology*, 44, 36-45.

Hepple, R. (2002). The role of O2 supply in muscle fatigue. *Canadian Journal of Applied Physiology*, 27(1), 56-69.

Hickson, R. C., Dvorak, B. A., Gorostiaga, E. M., Kurowski, T. T., & Foster, C. (1988). Potential for strength and endurance training to amplify endurance performance. *Journal of Applied Physiology,* 65(5), 2285-2290.

Huang, Y. C., Chang, K. H., Liou, T. H., Cheng, C. W., Lin, L. F., & Huang, S. W. (2017). Effects of kinesio taping for stroke patients with hemiplegic sholder pain: a double-blind, randomized, placebo-controlled study. *Journal of Rehabilitation Medicine, 49*(3), 208-215.

Hudson, A., Joulia, F., Butler, A., Fitzpatrick, R., Gandevia, S., & Butler, J. (2016). Activation of human inspiratory muscles in an upside-down posture. *Respiratory Physiology & Neurobiology*, 226, 152-159.

Implus LLC. (2020, June 25). How kinesiology tape work. Retrieved from https://www.rocktape.com/medical/products/rocktape/how-it-works/

Implus LLC. (2020, June 26). Tips for prevention of treatment of injuries for high school *athletes*. Retrieved from https://www.rocktape.com/project/tips-for-prevention-of-treatment-of-injuries-for-high-school-athletes/

Jaraczewska, E., & Long, C. (2006). Kinesio® taping in stroke: improving functional use of the upper extremity in hemiplegia. *Topics in Stroke Rehabilitation*, *13*(3), 31-42.

Jessop, A. (2020, June 6). How sports sponsorships allowed KT tape to turn selling kinesiology tape into a multi-million dollar business. Retrieved from https://www.forbes.com/sites/aliciajessop/2014/09/06/how-sports-sponsorships-allowed-kt-tape-to-turn-selling-kinesiology-tape-into-a-multi-million-dollar-business/#4fa8b4c2684e

Joyner, M. J., & Casey, D. P. (2015). Regulation of increased blood flow (hyperemia) to muscles during exercise: a hierarchy of competing physiological needs. *Physiological Reviews*, 95(2), 549-601.

Ju, Y. Y., Wang, C. W., & Cheng, H. Y. (2010). Effects of active fatiguing movement versus passive repetitive movement on knee proprioception. *Clinical Biomechanics*, 25(7), 708-712.

Kalichman, L., Levin, I., Bachar, I., & Vered, E. (2018). Short-term effects of kinesio taping on trigger points in upper trapezius and gastrocnemius muscles. *Journal of Bodywork Movement Therapies*, 22(3), 700-706.

Kase, K. (2011). *U.S. Patent No. 7,902,420*. Washington, DC: U.S. Patent and Trademark Office.

Kellis, E., & Baltzopoulos, V. (1996). Agonist and antagonist moment and EMG-angle relationship during isokinetic eccentric and concentric exercise . *Isokinetics and Exercise Science*, 6(3), 79-87.

Kinesio Co. (2019, June 25). *What is the kinesio taping method?* Retrieved from https://kinesiotaping.com/about/what-is-the-kinesio-taping-method/

Klika, V. (2011). *Biomechanics in applications*. Rijeka: Book on Demand.

Konrad, P. (2006). *The ABC of EMG. a practical introduction to kinesiological electromyography*. Scottsdale: Noraxon U.S.A, Inc.

KT Health LCC. (20120, April 2). *Preventative measures*. Retrieved from https://www.kttape.com/kinesiology-blog/post/preventative-measures/

KT Health, LCC. (2020, May 11). *Athletes performance says yes to kt tape*. Retrieved from https://www.kttape.com/kinesiology-blog/post/athletes-performance-says-yes-to-kt-tape/

Lee, N. H., Jung, H. C., Ok, G., & Lee, S. (2017). Acute effects of Kinesio taping on muscle function and self-perceived fatigue level in healthy adults. *European Journal of Sport Science*, *17*(6), 757-764.

Lins, C. A. A., Borges, D. T., Macedo, L. B., Costa, K. S. A., & Brasileiro, J. S. (2016). Delayed effect of kinesio taping on neuromuscular performance, balance, and lower limb function in healthy individuals: a randomized controlled trial. *Brazilian Journal of Physical Therapy*, 20(3), 231-239.

Luz Júnior, M., Almeida, M., Santos, R., Civile, V., & Costa, L. (2019). Effectiveness of kinesio taping in patients with chronic nonspecific low back pain: a systematic review with meta-analysis. *Spine,* 44(1), 68-78.

Metzler, D. E. (2003). Biochemistry: The chemical reactions of living cells. Elsevier.

Mine, K., Nakayama, T., Milanese, S., & Grimmer, K. (2018). Effects of kinesio tape on pain, muscle strength and functional performance: a systematic review of Japanese language literature. *Physical Therapy Reviews, 23*(2), 108-115.

Morris, D., Jones, D., Ryan, H., & Ryan, C. (2013). The clinical effects of Kinesio® Tex taping: A systematic review. *Physiotherapy Theory and Practice*, 29(4), 259-270.

Müller, C., & Brandes, M. (2015). Effect of kinesiotape applications on ball velocity and accuracy in amateur soccer and handball. *Journal of Human Kinetics*, 49(1), 119-129.

Murthy, G., Hargens, A., Lehman, S., & Rempel, D. (2006). Ischemia causes muscle fatigue. *Journal of Orthopaedic Research*, 19(3), 436-440.

Oliveira, A. K., Borges, D. T., Lins, C. A., Cavalcanti, R. L., Macedo, L. B., & Brasileiro, J. S. (2016). Immediate effects of Kinesio Taping® on neuromuscular performance of quadriceps and balance in individuals submitted to anterior cruciate ligament reconstruction: a randomized clinical trial. *Journal of Science and Medicine in Sport*, 19(1), 2-6.

Osternig, L. R., Hamill, J. O. S. E. P. H., Lander, J. E., & Robertson, R. I. C. H. A. R. D. (1986). Co-activation of sprinter and distance runner muscles in isokinetic exercise. *Medicine and Science in Sports and Exercise*, 18(4), 431-435.

Öztürk, G., Külcü, D. G., Mesci, N., Şilte, A. D., & Aydog, E. (2016). Efficacy of kinesio tape application on pain and muscle strength in patients with myofascial pain syndrome: a placebo-controlled trial. *Journal of Physical Therapy Science,* 28(4), 1074-1079.

Parker-Pope, T. (2020, August 9). A quirky athletic tape gets its olympic moment. Retrieved from https://well.blogs.nytimes.com/2008/08/19/a-quirky-athletic-tape-gets-its-olympic-moment/

Picchiotti, M. T., Weston, E. B., Knapik, G. G., Dufour, J. S., & Marras, W. S. (2019). Impact of two postural assist exoskeletons on biomechanical loading of the lumbar spine. *Applied Ergonomics*, 75, 1-7.

Pliner, J., Principe, A. H., Loshek, P., & Campbell-Kyureghyan, N. (2015, May). Can kinesiology tapes affect knee performance in healthy subjects? *Proceeding*s of *the* 36_{th} *IEEE Great Lakes Biomedical Conference*. IEEE.

Poon, K., Li, S., Roper, M., Wong, M., Wong, O., & Cheung, R. (2014). Kinesiology tape does not facilitate muscle performance: A deceptivecontrolled trial. *Manual Therapy*, 20(1), 130-133.

Ramírez-Vélez, R., Hormaz´abal-Aguayo, I., Izquierdo, M., Gonz´alez-Ru´ız, K., Correa-Bautista, J., & Garc´ıa-Hermoso, A. (2019). Effects of kinesio taping alone versus sham taping in individuals with musculoskeletal conditions after intervention for at least one week: A systematic review and meta-analysis. *Physiotherapy*, 105(4), 412-420.

Ramsook, A. H., Molgat-Seon, Y., Schaeffer, M. R., Wilkie, S. S., Camp, P. G., Reid, W. D., Lee, M. R.& Guenette, J. A. (2017). Effects of inspiratory muscle training on respiratory muscle electromyography and dyspnea during exercise in healthy men. *Journal of Applied Physiology*, 122(5), 1267-1275.

Reneker, J. C., Latham, L., McGlawn, R., & Reneker, M. R. (2018). Effectiveness of kinesiology tape on sports performance abilities in athletes: a systematic review. *Physical Therapy in Sport*, *31*, 83-98.

Ribeiro, F., & Mota, J. O. (2007). Effect of exercise-induced fatigue on position sense of the knee in the elderly. *European Journal of Applied Physiology*, 99(4), 379-385.

RocktapeAustralia. (2020, August 9). Rocktape application for carpal tunnel issues. Retrieved from https://www.youtube.com/watch?v=s2-wqgddzrg

Rodrigues-da-Silva, J. M., de Rezende, M. U., Spada, T. C., da Silva Francisco, L., Greve, J. M., & Ciolac, E. G. (2017). Effects of motor learning on clinical isokinetic test performance in knee osteoarthritis patients. *Clinics*, 72(4), 202-206.

Rutherford, D., Hubley-Kozey, C., & Stanish, W. (2011). Maximal voluntary isometric contraction exercises: a methodological investigation in moderate knee osteoarthritis. *Journal of Electromyography and Kinesiology*, 21(1), 154-160.

Schmidt, R. A., Lee, T. D., Winstein, C., Wulf, G., & Zelaznik, H. N. (2018). *Motor control and learning: A behavioral emphasis*. Champaign: Human kinetics.

Scott, B. R., Slattery, K. M., Sculley, D. V., Lockie, R. G., & Dascombe, B. J. (2014). Reliability of telemetric electromyography and near-infrared spectroscopy during high-intensity resistance exercise. *Journal of Electromyography and Kinesiology*, 24(5), 722-730.

Serra, M. V., Vieira, E. R., Brunt, D., Goethel, M. F., Gonçalves, M., & Quemelo, P. R. (2015). Kinesio taping effects on knee extension force among soccer players. *Brazilian Journal of Physical Therapy*, 19(2), 152-158.

Smith, K. J., & Billaut, F. (2010). Influence of cerebral and muscle oxygenation on repeated-sprint ability. *European Journal of Applied Physiology*, 109(5), 989-999.

Stedge, H. L., Kroskie, R. M., & Docherty, C. L. (2012). Kinesio taping and the circulation and endurance ratio of the gastrocnemius muscle. *Journal of Athletic Training*, 47(6), 635-642.

Thongpanja, S., Phinyomark, A., Phukpattaranont, P., & Limsakul, C. (2013). Mean and median frequency of EMG signal to determine muscle force based on time-dependent power spectrum. *Elektronika ir Elektrotechnika*, 19(3), 51-56.

Trecroci, A., Formenti, D., Rossi, A., Esposito, F., & Alberti, G. (2017). Acute effects of kinesio taping on a 6s maximal cycling sprint performance. *Research in Sports Medicine*, 25(1), 48-57.

Ulrey, B. L., & Fathallah, F. A. (2013). Effect of a personal weight transfer device on muscle activities and joint flexions in the stooped posture. *Journal of Electromyography and Kinesiology*, 23(1), 195-205.

Vercelli, S., Sartorio, F., Foti, C., Colletto, L., Virton, D., Ronconi, G., & Ferriero, G. (2012). Immediate effects of kinesiotaping on quadriceps muscle strength: a single-blind, placebo-controlled crossover trial. *Clinical Journal of Sport Medicine,* 22(4), 319-326.

Voight, M. L., Hardin, J. A., Blackburn, T. A., Tippett, S., & Canner, G. C. (1996). The effects of muscle fatigue on and the relationship of arm dominance to shoulder proprioception. *Journal of Orthopaedic & Sports Physical Therapy,* 23(6), 348-352.

Wang, J., & Chen, S. (2014). *Applied motor learning in physical education and sports*. Morgantown: Fitness Information Technology.

Wang, Y. W. (2018). The effect of kinesiology tape during isotonic knee flexion extension exercise on time to fatigue, rate, and quadricep muscle oxygenation (Master thesis, University of Wisconsin-Milwaukee). ProQuest Dissertations and Theses Global.

Wang, Y. W., Johnson, B., & Campbell-Kyureghyan, N. (2017). The effect of KT on knee flexion/extension performance in a fatiguing task. *IEEE Great Lakes Biomedical Conference (GLBC)*. Milwaukee: IEEE.

Williams, S., Whatman, C., Hume, P. A., & Sheerin, K. (2012). Kinesio taping in treatment and prevention of sports injuries meta-analysis of the evidence for its efectiveness. *Sports Medicine,* 42(2), 153-164.

Yam, M. L., Yang, Z., Zee, B. C.-Y., & Chong, K. C. (2019). Effects of kinesio tape on lower limb muscle strength, hop test, and vertical jump performances: a meta-analysis. *BMC Musculoskeletal Disorders*, 20(1), 212.

Appendices

Appendix A: Time to Fatigue

Table A1: TTF of the treatment knee

Subject	TTF (sec)						
	Session 1 (nKT)	Session 2 (0 hrs)	Session 3 (24 hrs)	Session 4 (48 hrs)	Session 5 (72 hrs)	Session 6 (nKT_1)	Session 7 (nKT_2)
1	93	79	92	118	116	155	95
2	38.2	40	41	46	49	49	62
3	103	167	159	188	218	234.5	244
4	181	217	270	182	211	316	255
5	65	71	92	79	82	79	92
6	100	93	75	81	92	141	130
7	293	282	324	375	441	467	420
8	45	51	56	59	65	66	72
9	42	45	51	59	44	49	49
10	25	26	21	31	17	30	23
11	35	33	40	32	35	35	35
12	50	48	19	20	23	23	27
13	53	43	57	57	57	86	74
14	69	77	47	48	38	50	51

Table A2: TTF of the control knee

Subject	TTF (sec)						
	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7
1	82	78	86	111	131	122	89
2	39	40	36	48	45	45	51
3	95.5	126	105.5	139	108	116.5	133
4	114	135	107	144	191	209	258
5	63	70	97	72	91	75	88
6	70	94	70	91	63	98.6	99.3
7	292	286	297	369	387	475	390
8	46	49	58	60	64	67	75
9	36	41	48	52	52	47	51
10	23	11	28	32	28	30	30
11	34	35	40	42	32	37	43
12	47	37	25	19	24	21	22
13	52	58	58	61	60	68	83
14	60	53	52	45	38	38	46

Table A3: One-sided paired T-test results for TTF of the treatment knee and control knee

Paired T-Test and CI: TTF_Session 2, TTF_Session 1

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
TTF_Session 2	12	74.0	68.6	19.8
TTF_Session 1	12	75.7	72.1	20.8

Estimation for Paired Difference

Mean	StDev	SE Mean	95% Lower Bound for μ_difference
-1.68	7.32	2.11	-5.48

μ_difference: mean of (TTF_Session 2 - TTF_Session 1)

Test

Null hypothesis H₀: μ_difference = 0
Alternative hypothesis H₁: μ_difference > 0

T-Value	P-Value
-0.80	0.779

CONTROL_PAIR-T

Paired T-Test and CI: TTF_2, TTF_1

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
TTF_2	14	79.5	69.0	18.4
TTF_1	14	75.3	67.3	18.0

Estimation for Paired Difference

Mean	StDev	SE Mean	95% Lower Bound for μ_difference
4.25	12.89	3.45	-1.85

μ_difference: population mean of (TTF_2 - TTF_1)

Test

Null hypothesis H_0: μ_difference = 0
Alternative hypothesis H_1: μ_difference > 0

T-Value	P-Value
1.23	0.120

Table A4: General Linear ANOVA results for the effect of duration on TTF in the treatment knee

General Linear Model: TTF percent change(%) versus Duration, Blocks

Method

Factor coding (-1, 0, +1)

Factor Information

Factor	Type	Levels	Values
Duration	Fixed	4	0, 24, 48, 72
Blocks	Fixed	14	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Duration	3	0.05207	0.01736	0.46	0.711
Blocks	13	4.27005	0.32847	8.71	0.000
Error	39	1.47014	0.03770		
Total	55	5.79226			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.194154	74.62%	64.21%	47.67%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	0.0916	0.0259	3.53	0.001	
Duration					
0	-0.0362	0.0449	-0.80	0.426	1.50
24	-0.0240	0.0449	-0.53	0.597	1.50
48	0.0262	0.0449	0.58	0.563	1.50
Blocks					
1	-0.0029	0.0935	-0.03	0.975	1.86
2	0.0602	0.0935	0.64	0.524	1.86
3	0.6851	0.0935	7.32	0.000	1.86
4	0.1238	0.0935	1.32	0.193	1.86
5	0.1545	0.0935	1.65	0.107	1.86
6	-0.2391	0.0935	-2.56	0.015	1.86
7	0.1217	0.0935	1.30	0.201	1.86
8	0.1917	0.0935	2.05	0.047	1.86
9	0.0929	0.0935	0.99	0.327	1.86
10	-0.1416	0.0935	-1.51	0.138	1.86
11	-0.0916	0.0935	-0.98	0.333	1.86
12	-0.5416	0.0935	-5.79	0.000	1.86
13	-0.0822	0.0935	-0.88	0.385	1.86

Table A5: General Linear ANOVA results for the effect of duration on TTF in the control knee

General Linear Model: Percent Change TTF(%) versus Duration, Blocks

Method

Factor coding	(-1, 0, +1)
Rows unused	1

Factor Information

Factor	Type	Levels	Values
Duration	Fixed	4	24, 48, 72, 96
Blocks	Fixed	14	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Duration	3	0.1606	0.05353	1.68	0.187
Blocks	13	2.3991	0.18455	5.80	0.000
Error	38	1.2082	0.03180		
Total	54	3.7828			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.178312	68.06%	54.61%	33.69%

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	0.1330	0.0241	5.51	0.000	
Duration					
24	-0.0515	0.0428	-1.20	0.236	1.56
48	-0.0562	0.0414	-1.36	0.183	1.51
72	0.0608	0.0414	1.47	0.151	1.51
Blocks					
1	0.1048	0.0860	1.22	0.230	1.86
2	-0.0496	0.0860	-0.58	0.567	1.86
3	0.1197	0.0860	1.39	0.172	1.86
4	0.1324	0.0860	1.54	0.132	1.86
5	0.1766	0.0860	2.05	0.047	1.86
6	0.0027	0.0860	0.03	0.975	1.86
7	0.0134	0.0860	0.16	0.877	1.86
8	0.1225	0.0860	1.42	0.163	1.86
9	0.2073	0.0860	2.41	0.021	1.86
10	0.1252	0.0992	1.26	0.215	2.16
11	-0.0374	0.0860	-0.43	0.666	1.86
12	-0.5745	0.0860	-6.68	0.000	1.86
13	0.0065	0.0860	0.08	0.941	1.86

Appendix B: Number of Cycles

Table B1: The number of cycles of the treatment knee

Subject	Number of cycles (count)						
	Session 1 (nKT)	Session 2 (0 hrs)	Session 3 (24 hrs)	Session 4 (48 hrs)	Session 5 (72 hrs)	Session 6 (nKT_1)	Session 7 (nKT_2)
1	47	43	49	61	60	82	63
2	37	40	39	46	47	47	58
3	86	143	141.5	164	186.5	210	215
4	192	161	211	137	164	253.5	177
5	51.5	60	71	64	67	68	73
6	70	59	51	49	55	107	97
7	238	231	272	334	380	432	372
8	36	43	47	54	57	57	63
9	32	33	38	41	36	40	46
10	20	23	20	30	17	30	25
11	28	29	35	30	34	32	32
12	48	46	23	26	29	27	32
13	52	45	55	56	54	76	66
14	53	72	42	48	36	51	50

Table B2: The number of cycles results of the control knee

Subject	Number of cycles (count)						
	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7
1	39	43	43	55	68	66	51.52632
2	38	40	35	47	43	43	48
3	74	82	90	114	90	99	108
4	92	102.5	88	117	159.5	164.5	199.5
5	54	56.5	80	59.5	76	63	74.5
6	41	58	44	57	37	67	69
7	236	240	256	312	341	404	348
8	37	42	49	52	54	60	65
9	30	32	40	41	40	42	48
10	20	7	22	26	25	25	29
11	32	33	37	38	36	34	39
12	45	37	25	23	29	26	26
13	45	48	51	55	52	62	70
14	54	46	44	46	43	36	44

Table B3: One-sided paired T-test results for the number of cycles in the treatment knee

Paired T-Test and CI: Number of Cycles_Session 2, Number of Cycles_Session 1

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
Number of Cycles_Session 2	12	60.3	55.5	16.0
Number of Cycles_Session 1	12	59.4	57.8	16.7

Estimation for Paired Difference

Mean	StDev	SE Mean	95% Lower Bound for μ_difference
0.96	8.15	2.35	-3.27

μ_difference: mean of (Number of Cycles_Session 2 - Number of Cycles_Session 1)

Test

Null hypothesis	H_0: μ_difference = 0
Alternative hypothesis	H_1: μ_difference > 0

T-Value	P-Value
0.41	0.346

CONTROL_PAIR-T

Paired T-Test and CI: Num_2, Num_1

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
Num_2	12	64.8	58.3	16.8
Num_1	12	61.9	57.2	16.5

Estimation for Paired Difference

Mean	StDev	SE Mean	95% Lower Bound for μ_difference
2.95	6.87	1.98	-0.61

μ_difference: population mean of (Num_2 - Num_1)

Test

Null hypothesis	H_0: μ_difference = 0
Alternative hypothesis	H_1: μ_difference > 0

T-Value	P-Value
1.49	0.082

Table B4: General Linear ANOVA results for the effect of duration on the number of cycles in the treatment knee

General Linear Model: Number of cycles % Change versus Duration, Blocks

Method

Factor coding	(-1, 0, +1)

Factor Information

Factor	Type	Levels	Values
Duration	Fixed	4	0, 24, 48, 72
Blocks	Fixed	14	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Duration	3	0.1121	0.03737	1.05	0.381
Blocks	13	4.4502	0.34232	9.64	0.000
Error	39	1.3855	0.03553		
Total	55	5.9478			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.188484	76.71%	67.15%	51.97%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	0.1243	0.0252	4.94	0.000	
Duration					
0	-0.0475	0.0436	-1.09	0.283	1.50
24	-0.0419	0.0436	-0.96	0.343	1.50
48	0.0464	0.0436	1.06	0.294	1.50
Blocks					
1	0.0087	0.0908	0.10	0.924	1.86
2	0.0379	0.0908	0.42	0.679	1.86
3	0.7216	0.0908	7.95	0.000	1.86
4	-0.2480	0.0908	-2.73	0.009	1.86
5	0.1475	0.0908	1.62	0.112	1.86
6	-0.3614	0.0908	-3.98	0.000	1.86
7	0.1541	0.0908	1.70	0.098	1.86
8	0.2715	0.0908	2.99	0.005	1.86
9	0.0319	0.0908	0.35	0.727	1.86
10	0.0007	0.0908	0.01	0.994	1.86
11	0.0171	0.0908	0.19	0.852	1.86
12	-0.4785	0.0908	-5.27	0.000	1.86
13	-0.1147	0.0908	-1.26	0.214	1.86

Table B5: General Linear ANOVA results for the effect of duration on the number of cycles in the control knee

General Linear Model: Number of cycles % change versus Duration, Blocks

Method

Factor coding	(-1, 0, +1)
Rows unused	1

Factor Information

Factor	Type	Levels	Values
Duration	Fixed	4	24, 48, 72, 96
Blocks	Fixed	14	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Duration	3	0.3181	0.10604	3.54	0.023
Blocks	13	2.0324	0.15634	5.22	0.000
Error	38	1.1380	0.02995		
Total	54	3.4968			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.173054	67.46%	53.75%	32.59%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	0.1549	0.0234	6.62	0.000	
Duration					
24	-0.0876	0.0416	-2.11	0.042	1.56
48	-0.0642	0.0402	-1.60	0.119	1.51
72	0.0681	0.0402	1.69	0.099	1.51
Blocks					
1	0.1848	0.0835	2.21	0.033	1.86
2	-0.0694	0.0835	-0.83	0.411	1.86
3	0.1153	0.0835	1.38	0.175	1.86
4	0.1141	0.0835	1.37	0.180	1.86
5	0.1043	0.0835	1.25	0.219	1.86
6	0.0483	0.0835	0.58	0.566	1.86
7	0.0622	0.0835	0.75	0.461	1.86
8	0.1761	0.0835	2.11	0.041	1.86
9	0.1201	0.0835	1.44	0.158	1.86
10	0.0325	0.0963	0.34	0.737	2.16
11	-0.0299	0.0835	-0.36	0.722	1.86
12	-0.5216	0.0835	-6.25	0.000	1.86
13	-0.0105	0.0835	-0.13	0.901	1.86

Appendix C: Time to Minimum rSO_2 (TTM)

Table C1: TTM of VL of the treatment knee

Subject	TTM (sec)						
	Session 1 (nKT)	Session 2 (0 hrs)	Session 3 (24 hrs)	Session 4 (48 hrs)	Session 5 (72 hrs)	Session 6 (nKT_1)	Session 7 (nKT_2)
1	47	43	49	61	60	82	63
2	37	40	39	46	47	47	58
3	86	143	141.5	164	186.5	210	215
4	192	161	211	137	164	253.5	177
5	51.5	60	71	64	67	68	73
6	70	59	51	49	55	107	97
7	238	231	272	334	380	432	372
8	36	43	47	54	57	57	63
9	32	33	38	41	36	40	46
10	20	23	20	30	17	30	25
11	28	29	35	30	34	32	32
12	48	46	23	26	29	27	32
13	52	45	55	56	54	76	66
14	53	72	42	48	36	51	50

Table C2: TTM of VM of the treatment knee

Subject	TTM (sec)						
	Session 1 (nKT)	Session 2 (0 hrs)	Session 3 (24 hrs)	Session 4 (48 hrs)	Session 5 (72 hrs)	Session 6 (nKT_1)	Session 7 (nKT_2)
1	29	84	80	32	96	140	95
2	24	20	20	20	20	24	16
3	80	144	144	168	212	204	224
4	20	32	36	24	28	36	20
5	24	32	20	20	16	32	52
6	20	28	28	40	64	37	29
7	204	76	152	144	224	172	108
8	16	16	16	16	16	20	16
9	20	20	20	20	20	24	20
10	16	24	20	24	16	24	16
11	12	12	16	16	16	16	16
12	48	40	19	20	23	23	20
13	44	36	56	48	56	28	44
14	14	12	16	12	12	8	8

Table C3: TTM of VL results of the control knee

Subject	TTM (sec)						
	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7
1	80	72	40	60	68	76	32
2	24	24	24	24	20	28	20
3	88	16	20	116	20	28	20
4	24	20	24	24	20	20	24
5	16	24	20	36	28	72	28
6	16	20	24	28	12	28	5
7	100	172	144	148	152	248	20
8	16	20	20	20	16	16	16
9	24	24	24	20	28	16	24
10	12	4	20	20	28	16	30
11	20	32	24	20	20	32	20
12	24	20	25	16	24	21	20
13	32	32	52	36	40	32	56
14	20	16	20	16	24	12	12

Table C4: TTM of VM results of the control knee

Subject	TTM (sec)						
	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7
1	39	43	43	55	68	66	51.52632
2	38	40	35	47	43	43	48
3	74	82	90	114	90	99	108
4	92	102.5	88	117	159.5	164.5	199.5
5	54	56.5	80	59.5	76	63	74.5
6	41	58	44	57	37	67	69
7	236	240	256	312	341	404	348
8	37	42	49	52	54	60	65
9	30	32	40	41	40	42	48
10	20	7	22	26	25	25	29
11	32	33	37	38	36	34	39
12	45	37	25	23	29	26	26
13	45	48	51	55	52	62	70
14	54	46	44	46	43	36	44

Table C5: Paired T-test results for TTM of VL o the treatment knee and control knee

Paired T-Test and CI: TTM_VL_Sess.2, TTM_VL_Sess.1

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
TTM_VL_Sess.2	14	0.4247	0.2018	0.0539
TTM_VL_Sess.1	14	0.4969	0.2514	0.0672

Estimation for Paired Difference

Mean	StDev	SE Mean	95% Lower Bound for µ_difference
-0.0722	0.2325	0.0621	-0.1823

µ_difference: population mean of (TTM_VL_Sess.2 - TTM_VL_Sess.1)

Test

Null hypothesis H₀: µ_difference = 0
Alternative hypothesis H₁: µ_difference > 0

T-Value	P-Value
-1.16	0.867

CONTROL_PAIR-T

Paired T-Test and CI: TTM_VL2, TTM_VL1

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
TTM_VL2	12	0.3988	0.2336	0.0674
TTM_VL1	12	0.4270	0.2476	0.0715

Estimation for Paired Difference

Mean	StDev	SE Mean	95% Lower Bound for µ_difference
-0.0282	0.0465	0.0134	-0.0523

µ_difference: population mean of (TTM_VL2 - TTM_VL1)

Test

Null hypothesis H_0: µ_difference = 0
Alternative hypothesis H_1: µ_difference > 0

T-Value	P-Value
-2.10	0.970

Table C6: Paired T-test results for TTM of VM of the treatment knee and control knee

Paired T-Test and CI: TTM_VM_Sess.2, TTM_VM_Sess.1

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
TTM_VM_Sess.2	14	0.4338	0.2581	0.0690
TTM_VM_Sess.1	14	0.4388	0.2575	0.0688

Estimation for Paired Difference

Mean	StDev	SE Mean	95% Lower Bound for μ_difference
-0.0050	0.1587	0.0424	-0.0801

μ_difference: population mean of (TTM_VM_Sess.2 - TTM_VM_Sess.1)

Test

Null hypothesis	H_0: μ_difference = 0
Alternative hypothesis	H_1: μ_difference > 0

T-Value	P-Value
-0.12	0.546

CONTROL_PAIR-T

Paired T-Test and CI: TTM_VM2, TTM_VM1

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
TTM_VM2	14	0.4729	0.2494	0.0667
TTM_VM1	14	0.5094	0.2416	0.0646

Estimation for Paired Difference

Mean	StDev	SE Mean	95% Lower Bound for μ_difference
-0.0365	0.2545	0.0680	-0.1570

μ_difference: population mean of (TTM_VM2 - TTM_VM1)

Test

Null hypothesis	H_0: μ_difference = 0
Alternative hypothesis	H_1: μ_difference > 0

T-Value	P-Value
-0.54	0.700

Table C7: General Linear ANOVA results for the effect of duration on TTM of VL of the treatment knee

General Linear Model: %Difference_TTM_VL versus Duration, Blocks

Method

Factor coding (-1, 0, +1)

Factor Information

Factor	Type	Levels	Values
Duration	Fixed	4	0, 24, 48, 72
Blocks	Fixed	14	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Duration	3	0.02908	0.009692	0.37	0.778
Blocks	13	2.08472	0.160363	6.06	0.000
Error	39	1.03217	0.026466		
Total	55	3.14597			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.162683	67.19%	53.73%	32.35%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	-0.0358	0.0217	-1.65	0.107	
Duration					
0	-0.0364	0.0377	-0.97	0.339	1.50
24	0.0014	0.0377	0.04	0.970	1.50
48	0.0093	0.0377	0.25	0.807	1.50
Blocks					
1	0.0855	0.0784	1.09	0.282	1.86
2	0.1550	0.0784	1.98	0.055	1.86
3	-0.0764	0.0784	-0.97	0.336	1.86
4	0.0228	0.0784	0.29	0.773	1.86
5	-0.0844	0.0784	-1.08	0.288	1.86
6	0.0747	0.0784	0.95	0.346	1.86
7	-0.2438	0.0784	-3.11	0.003	1.86
8	0.0531	0.0784	0.68	0.502	1.86
9	-0.0243	0.0784	-0.31	0.758	1.86
10	-0.0079	0.0784	-0.10	0.920	1.86
11	0.1203	0.0784	1.54	0.133	1.86
12	0.4330	0.0784	5.52	0.000	1.86
13	-0.4501	0.0784	-5.74	0.000	1.86

Table C8: General Linear ANOVA results for the effect of duration on TTM of VM of the treatment knee

General Linear Model: %Difference_TTM_VM versus Duration, Blocks

Method

Factor coding (-1, 0, +1)

Factor Information

Factor	Type	Levels	Values
Duration	Fixed	4	0, 24, 48, 72
Blocks	Fixed	14	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Duration	3	0.03053	0.010176	1.49	0.234
Blocks	13	1.00577	0.077367	11.29	0.000
Error	39	0.26723	0.006852		
Total	55	1.30353			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0827769	79.50%	71.09%	57.73%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	0.0187	0.0111	1.69	0.099	
Duration					
0	-0.0237	0.0192	-1.24	0.224	1.50
24	0.0171	0.0192	0.89	0.378	1.50
48	-0.0222	0.0192	-1.16	0.253	1.50
Blocks					
1	-0.0866	0.0399	-2.17	0.036	1.86
2	0.0201	0.0399	0.51	0.616	1.86
3	-0.0311	0.0399	-0.78	0.440	1.86
4	-0.0061	0.0399	-0.15	0.880	1.86
5	-0.0473	0.0399	-1.19	0.243	1.86
6	0.2473	0.0399	6.20	0.000	1.86
7	-0.3073	0.0399	-7.71	0.000	1.86
8	-0.0951	0.0399	-2.38	0.022	1.86
9	-0.0874	0.0399	-2.19	0.035	1.86
10	0.2390	0.0399	5.99	0.000	1.86
11	0.0686	0.0399	1.72	0.093	1.86
12	-0.0204	0.0399	-0.51	0.613	1.86
13	0.0622	0.0399	1.56	0.127	1.86

Table C9: General Linear ANOVA results for the effect of duration on TTM of VL of the control knee

General Linear Model: % Difference in TTM of VL versus Duration, Blocks

Method

Factor coding	(-1, 0, +1)
Rows unused	1

Factor Information

Factor	Type	Levels	Values
Duration	Fixed	4	24, 48, 72, 96
Blocks	Fixed	14	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Duration	3	0.09232	0.03077	1.71	0.181
Blocks	13	3.42111	0.26316	14.63	0.000
Error	38	0.68359	0.01799		
Total	54	4.18402			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.134123	83.66%	76.78%	65.48%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	-0.0641	0.0182	-3.53	0.001	
Duration					
24	-0.0483	0.0322	-1.50	0.142	1.56
48	0.0639	0.0312	2.05	0.047	1.51
72	0.0038	0.0312	0.12	0.902	1.51
Blocks					
1	-0.5853	0.0647	-9.05	0.000	1.86
2	-0.2553	0.0647	-3.95	0.000	1.86
3	0.0076	0.0647	0.12	0.907	1.86
4	0.0152	0.0647	0.24	0.815	1.86
5	0.0218	0.0647	0.34	0.738	1.86
6	0.1318	0.0647	2.04	0.049	1.86
7	0.5049	0.0647	7.81	0.000	1.86
8	-0.0865	0.0647	-1.34	0.189	1.86
9	-0.1021	0.0647	-1.58	0.123	1.86
10	-0.1536	0.0746	-2.06	0.046	2.16
11	0.0190	0.0647	0.29	0.770	1.86
12	0.3475	0.0647	5.37	0.000	1.86
13	-0.0000	0.0647	-0.00	1.000	1.86

Table C10: General Linear ANOVA results for the effect of duration on TTM of VM of the control knee

General Linear Model: % Difference in TTM of VM versus Duration, Blocks

Method

Factor coding	(-1, 0, +1)
Rows unused	1

Factor Information

Factor	Type	Levels	Values
Duration	Fixed	4	24, 48, 72, 96
Blocks	Fixed	14	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Duration	3	0.07136	0.02379	1.52	0.226
Blocks	13	0.89363	0.06874	4.38	0.000
Error	38	0.59618	0.01569		
Total	54	1.56245			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.125255	61.84%	45.78%	18.48%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	0.0391	0.0170	2.31	0.027	
Duration					
24	0.0035	0.0301	0.12	0.908	1.56
48	0.0463	0.0291	1.59	0.120	1.51
72	-0.0541	0.0291	-1.86	0.071	1.51
Blocks					
1	-0.1518	0.0604	-2.51	0.016	1.86
2	-0.0672	0.0604	-1.11	0.273	1.86
3	-0.0943	0.0604	-1.56	0.127	1.86
4	-0.0825	0.0604	-1.37	0.180	1.86
5	-0.0421	0.0604	-0.70	0.490	1.86
6	-0.0042	0.0604	-0.07	0.945	1.86
7	0.0885	0.0604	1.46	0.151	1.86
8	-0.0529	0.0604	-0.87	0.387	1.86
9	-0.2037	0.0604	-3.37	0.002	1.86
10	0.2201	0.0697	3.16	0.003	2.16
11	0.0265	0.0604	0.44	0.663	1.86
12	0.2959	0.0604	4.90	0.000	1.86
13	0.0218	0.0604	0.36	0.720	1.86

Appendix D: Rate of rSO_2

Table D1: Rate of rSO_2 of VL of the treatment knee

Subject	Rate of rSO_2 (rSO_2/sec)						
	Session 1 (nKT)	Session 2 (0 hrs)	Session 3 (24 hrs)	Session 4 (48 hrs)	Session 5 (72 hrs)	Session 6 (nKT_1)	Session 7 (nKT_2)
1	1.16	1.08	0.72	1.30	0.90	0.87	0.80
2	1.05	0.83	0.68	0.63	0.70	0.50	0.65
3	1.47	1.75	1.84	1.29	1.15	2.00	0.16
4	2.31	2.60	2.69	2.35	1.79	2.41	1.80
5	2.78	2.58	1.14	1.84	1.38	1.12	1.38
6	1.29	1.43	1.72	1.82	1.00	1.37	1.10
7	0.20	0.40	0.49	0.14	0.20	0.28	0.50
8	2.20	0.90	1.30	1.59	1.70	1.78	1.99
9	1.35	1.05	1.30	0.94	1.20	1.13	1.43
10	0.24	0.13	0.29	0.19	0.45	0.38	0.38
11	2.39	1.46	1.40	2.29	1.95	1.80	2.38
12	2.36	1.68	3.64	3.24	1.93	4.29	3.50
13	0.27	1.66	1.10	0.86	0.42	0.56	0.59
14	2.999	3.00	3.31	3.30	2.94	4.42	2.39

Table D2: Rate of rSO_2 of VL the control knee

Subject	Rate of rSO_2 (rSO_2/sec)						
	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7
1	0.67	0.66	1.61	0.77	1.08	0.45	1.71
2	0.59	1.01	0.46	0.75	0.63	0.73	0.84
3	1.44	2.21	1.06	1.53	1.80	2.46	1.85
4	2.41	2.53	2.29	1.88	2.03	2.15	1.90
5	2.18	2.40	2.23	1.40	1.76	1.17	1.51
6	1.54	1.04	1.33	0.99	0.71	1.44	1.80
7	0.88	0.45	0.17	0.11	0.16	0.11	0.22
8	1.82	1.34	2.05	1.16	1.31	1.50	2.63
9	0.58	0.54	0.76	0.64	0.38	0.55	0.43
10	0.31	0.27	0.27	0.29	0.28	0.10	0.16
11	2.20	1.95	2.20	2.64	2.49	1.73	3.80
12	2.23	2.68	2.05	3.30	2.55	2.25	2.08
13	0.36	0.58	0.55	0.65	0.48	0.51	0.51
14	2.01	2.14	1.46	2.86	2.61	2.94	3.67

Table D3 Rate of rSO_2 of VM of the treatment knee

Subject	Rate of rSO_2 (rSO_2/sec)						
	Session 1 (nKT)	Session 2 (0 hrs)	Session 3 (24 hrs)	Session 4 (48 hrs)	Session 5 (72 hrs)	Session 6 (nKT_1)	Session 7 (nKT_2)
1	1.16	1.08	0.72	1.30	0.90	0.87	0.80
2	1.05	0.83	0.68	0.63	0.70	0.50	0.65
3	1.47	1.75	1.84	1.29	1.15	2.00	0.16
4	2.31	2.60	2.69	2.35	1.79	2.41	1.80
5	2.78	2.58	1.14	1.84	1.38	1.12	1.38
6	1.29	1.43	1.72	1.82	1.00	1.37	1.10
7	0.20	0.40	0.49	0.14	0.20	0.28	0.50
8	2.20	0.90	1.30	1.59	1.70	1.78	1.99
9	1.35	1.05	1.30	0.94	1.20	1.13	1.43
10	0.24	0.13	0.29	0.19	0.45	0.38	0.38
11	2.39	1.46	1.40	2.29	1.95	1.80	2.38
12	2.36	1.68	3.64	3.24	1.93	4.29	3.50
13	0.27	1.66	1.10	0.86	0.42	0.56	0.59
14	2.999	3.00	3.31	3.30	2.94	4.42	2.39

Table D4: Rate of rSO_2 of VM the control knee

Subject	Rate of rSO_2 (rSO_2/sec)						
	Session 1 (nKT)	Session 2 (0 hrs)	Session 3 (24 hrs)	Session 4 (48 hrs)	Session 5 (72 hrs)	Session 6 (nKT_1)	Session 7 (nKT_2)
1	0.67	0.66	1.61	0.77	1.08	0.45	1.71
2	0.59	1.01	0.46	0.75	0.63	0.73	0.84
3	1.44	2.21	1.06	1.53	1.80	2.46	1.85
4	2.41	2.53	2.29	1.88	2.03	2.15	1.90
5	2.18	2.40	2.23	1.40	1.76	1.17	1.51
6	1.54	1.04	1.33	0.99	0.71	1.44	1.80
7	0.88	0.45	0.17	0.11	0.16	0.11	0.22
8	1.82	1.34	2.05	1.16	1.31	1.50	2.63
9	0.58	0.54	0.76	0.64	0.38	0.55	0.43
10	0.31	0.27	0.27	0.29	0.28	0.10	0.16
11	2.20	1.95	2.20	2.64	2.49	1.73	3.80
12	2.23	2.68	2.05	3.30	2.55	2.25	2.08
13	0.36	0.58	0.55	0.65	0.48	0.51	0.51
14	2.01	2.14	1.46	2.86	2.61	2.94	3.67

Table D5: Paired T-test results for drop rate of rSO_2 of VL in the treatment knee and control knee

Paired T-Test and CI: DropRaterSO2_VL_Session2, DropRaterSO2_VL_Session1

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
DropRaterSO2_VL_Session2	14	0.4574	0.3102	0.0829
DropRaterSO2_VL_Session1	14	0.4469	0.3102	0.0829

Estimation for Paired Difference

Mean	StDev	SE Mean	95% CI for μ_difference
0.0104	0.1426	0.0381	(-0.0719, 0.0928)

μ_difference: mean of (DropRaterSO2_VL_Session2 - DropRaterSO2_VL_Session1)

Test

Null hypothesis	H_0: μ_difference = 0
Alternative hypothesis	H_1: μ_difference ≠ 0

T-Value	P-Value
0.27	0.788

CONTROL_PAIR-T

Paired T-Test and CI: DropRaterSO2_VL_Session2, DropRaterSO2_VL_Session1

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
DropRaterSO2_VL_Session2	14	0.420	0.388	0.104
DropRaterSO2_VL_Session1	14	0.439	0.318	0.085

Estimation for Paired Difference

Mean	StDev	SE Mean	95% CI for μ_difference
-0.0191	0.1463	0.0391	(-0.1035, 0.0654)

μ_difference: mean of (DropRaterSO2_VL_Session2 - DropRaterSO2_VL_Session1)

Test

Null hypothesis	H_0: μ_difference = 0
Alternative hypothesis	H_1: μ_difference ≠ 0

T-Value	P-Value
-0.49	0.634

Table D6: Paired T-test results for drop rate of rSO_2 of VM in the treatment knee and control knee

Paired T-Test and CI: DropRaterSO2_VM_Session2, DropRaterSO2_VM_Session1

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
DropRaterSO2_VM_Session2	14	0.1985	0.1712	0.0457
DropRaterSO2_VM_Session1	14	0.2070	0.1439	0.0385

Estimation for Paired Difference

Mean	StDev	SE Mean	95% CI for μ_difference
-0.0085	0.1374	0.0367	(-0.0878, 0.0709)

μ_difference: mean of (DropRaterSO2_VM_Session2 - DropRaterSO2_VM_Session1)

Test

Null hypothesis	H_0: μ_difference = 0
Alternative hypothesis	H_1: μ_difference ≠ 0

T-Value	P-Value
-0.23	0.821

CONTROL_PAIR-T

Paired T-Test and CI: DropRaterSO2_VM_Session2, DropRaterSO2_VM_Session1

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
DropRaterSO2_VM_Session2	14	0.2010	0.2182	0.0583
DropRaterSO2_VM_Session1	14	0.2068	0.1560	0.0417

Estimation for Paired Difference

Mean	StDev	SE Mean	95% CI for μ_difference
-0.0058	0.0889	0.0238	(-0.0571, 0.0456)

μ_difference: mean of (DropRaterSO2_VM_Session2 - DropRaterSO2_VM_Session1)

Test

Null hypothesis	H_0: μ_difference = 0
Alternative hypothesis	H_1: μ_difference ≠ 0

T-Value	P-Value
-0.24	0.812

Table D7: General Linear ANOVA results for the effect of duration on drop rate of rSO_2 of VL in the treatment knee

General Linear Model: DropRaterSO2_VL versus Duration, Blocks

Method

Factor coding (-1, 0, +1)

Factor Information

Factor	Type	Levels	Values
Duration	Fixed	4	0, 24, 48, 72
Blocks	Fixed	14	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Duration	3	0.1074	0.03580	0.36	0.786
Blocks	13	8.8714	0.68242	6.77	0.000
Error	39	3.9307	0.10079		
Total	55	12.9095			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.317470	69.55%	57.06%	37.22%

Coefficients

Term	Coef	SE Coef	95% CI	T-Value	P-Value	VIF
Constant	0.0713	0.0424	(-0.0145, 0.1571)	1.68	0.101	
Duration						
0	-0.0609	0.0735	(-0.2095, 0.0878)	-0.83	0.412	1.50
24	0.0389	0.0735	(-0.1098, 0.1875)	0.53	0.600	1.50
48	0.0443	0.0735	(-0.1044, 0.1929)	0.60	0.550	1.50
72	-0.0223	0.0735	(-0.1709, 0.1264)	-0.30	0.764	*
Blocks						
1	0.003	0.153	(-0.306, 0.312)	0.02	0.984	1.86
2	-0.168	0.153	(-0.477, 0.142)	-1.10	0.280	1.86
3	-0.117	0.153	(-0.427, 0.192)	-0.77	0.448	1.86
4	-0.068	0.153	(-0.378, 0.241)	-0.45	0.658	1.86
5	-0.384	0.153	(-0.693, -0.075)	-2.51	0.016	1.86
6	0.034	0.153	(-0.275, 0.343)	0.22	0.825	1.86
7	-0.113	0.153	(-0.422, 0.196)	-0.74	0.465	1.86
8	-0.257	0.153	(-0.566, 0.053)	-1.68	0.101	1.86
9	-0.307	0.153	(-0.617, 0.002)	-2.01	0.052	1.86
10	-0.011	0.153	(-0.320, 0.299)	-0.07	0.944	1.86
11	-0.104	0.153	(-0.413, 0.206)	-0.68	0.502	1.86
12	1.351	0.153	(1.041, 1.660)	8.83	0.000	1.86
13	0.021	0.153	(-0.288, 0.330)	0.14	0.891	1.86
14	0.120	0.153	(-0.189, 0.429)	0.78	0.437	*

Table D8: General Linear ANOVA results for the effect of duration on drop rate of rSO_2 of VL in the control knee

General Linear Model: Difference_rSO2_VL versus Duration, Blocks

Method

Factor coding (-1, 0, +1)

Factor Information

Factor	Type	Levels	Values
Duration	Fixed	4	0, 24, 48, 72
Blocks	Fixed	14	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14

Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Duration	3	0.08663	1.09%	0.08663	0.02888	0.57	0.635
Blocks	13	5.87895	74.19%	5.87895	0.45223	9.00	0.000
Error	39	1.95870	24.72%	1.95870	0.05022		
Total	55	7.92428	100.00%				

Model Summary

S	R-sq	R-sq(adj)	PRESS	R-sq(pred)	AICc	BIC
0.224105	75.28%	65.14%	4.03844	49.04%	25.64	43.61

Term	Coef	SE Coef	95% CI	T-Value	P-Value	VIF
Constant	0.0412	0.0299	(-0.0194, 0.1017)	1.37	0.177	
Duration						
0	-0.0602	0.0519	(-0.1651, 0.0447)	-1.16	0.253	1.50
24	0.0332	0.0519	(-0.0717, 0.1382)	0.64	0.525	1.50
48	0.0369	0.0519	(-0.0680, 0.1418)	0.71	0.481	1.50
72	-0.0099	0.0519	(-0.1148, 0.0950)	-0.19	0.850	*
Blocks						
1	-0.382	0.108	(-0.600, -0.164)	-3.54	0.001	1.86
2	-0.233	0.108	(-0.451, -0.014)	-2.15	0.037	1.86
3	-0.042	0.108	(-0.260, 0.176)	-0.39	0.699	1.86
4	-0.097	0.108	(-0.315, 0.121)	-0.90	0.375	1.86
5	-0.035	0.108	(-0.253, 0.184)	-0.32	0.750	1.86
6	0.155	0.108	(-0.063, 0.373)	1.43	0.159	1.86
7	-0.050	0.108	(-0.269, 0.168)	-0.47	0.643	1.86
8	-0.372	0.108	(-0.590, -0.153)	-3.44	0.001	1.86
9	-0.156	0.108	(-0.375, 0.062)	-1.45	0.156	1.86
10	-0.132	0.108	(-0.351, 0.086)	-1.22	0.229	1.86
11	0.048	0.108	(-0.170, 0.267)	0.45	0.657	1.86
12	0.978	0.108	(0.760, 1.197)	9.06	0.000	1.86
13	0.015	0.108	(-0.204, 0.233)	0.14	0.893	1.86
14	0.302	0.108	(0.084, 0.521)	2.80	0.008	*

Table D9: General Linear ANOVA results for the effect of duration on drop rate of rSO_2 of VM in the treatment knee

General Linear Model: DropRaterSO2_VM versus Duration, Blocks

Method

Factor coding (-1, 0, +1)

Factor Information

Factor	Type	Levels	Values
Duration	Fixed	4	0, 24, 48, 72
Blocks	Fixed	14	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14

Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Duration	3	0.1026	1.17%	0.1026	0.03422	0.61	0.611
Blocks	13	6.4950	74.00%	6.4950	0.49962	8.94	0.000
Error	39	2.1794	24.83%	2.1794	0.05588		
Total	55	8.7771	100.00%				

Model Summary

S	R-sq	R-sq(adj)	PRESS	R-sq(pred)	AICc	BIC
0.236393	75.17%	64.98%	4.49344	48.80%	31.61	49.58

Coefficients

Term	Coef	SE Coef	95% CI	T-Value	P-Value	VIF
Constant	0.0513	0.0316	(-0.0126, 0.1152)	1.62	0.113	
Duration						
0	-0.0596	0.0547	(-0.1703, 0.0511)	-1.09	0.283	1.50
24	0.0493	0.0547	(-0.0613, 0.1600)	0.90	0.373	1.50
48	0.0305	0.0547	(-0.0801, 0.1412)	0.56	0.580	1.50
72	-0.0203	0.0547	(-0.1310, 0.0904)	-0.37	0.713	*
Blocks						
1	0.150	0.114	(-0.081, 0.380)	1.32	0.196	1.86
2	-0.285	0.114	(-0.516, -0.055)	-2.51	0.017	1.86
3	-0.101	0.114	(-0.331, 0.129)	-0.89	0.381	1.86
4	-0.137	0.114	(-0.367, 0.093)	-1.20	0.237	1.86
5	-0.237	0.114	(-0.468, -0.007)	-2.08	0.044	1.86
6	-0.036	0.114	(-0.266, 0.194)	-0.32	0.753	1.86
7	-0.084	0.114	(-0.314, 0.146)	-0.74	0.466	1.86
8	-0.217	0.114	(-0.448, 0.013)	-1.91	0.064	1.86
9	-0.238	0.114	(-0.468, -0.007)	-2.09	0.044	1.86
10	0.051	0.114	(-0.180, 0.281)	0.44	0.659	1.86
11	-0.064	0.114	(-0.294, 0.166)	-0.56	0.578	1.86
12	1.146	0.114	(0.916, 1.377)	10.06	0.000	1.86
13	0.047	0.114	(-0.183, 0.278)	0.42	0.680	1.86
14	0.005	0.114	(-0.225, 0.235)	0.04	0.965	*

Table D10: General Linear ANOVA results for the effect of duration on drop rate of rSO_2 of VM in the control knee

General Linear Model: Difference_rSO2_VM versus Duration, Blocks

Method

Factor coding (-1, 0, +1)

Factor Information

Factor	Type	Levels	Values
Duration	Fixed	4	0, 24, 48, 72
Blocks	Fixed	14	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14

Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Duration	3	0.1218	3.24%	0.1218	0.04061	1.03	0.391
Blocks	13	2.0950	55.72%	2.0950	0.16116	4.07	0.000
Error	39	1.5431	41.04%	1.5431	0.03957		
Total	55	3.7599	100.00%				

Model Summary

S	R-sq	R-sq(adj)	PRESS	R-sq(pred)	AICc	BIC
0.198911	58.96%	42.12%	3.18148	15.38%	12.28	30.25

Coefficients

Term	Coef	SE Coef	95% CI	T-Value	P-Value	VIF
Constant	0.0355	0.0266	(-0.0182, 0.0893)	1.34	0.189	
Duration						
0	-0.0413	0.0460	(-0.1344, 0.0518)	-0.90	0.375	1.50
24	-0.0122	0.0460	(-0.1053, 0.0809)	-0.27	0.792	1.50
48	0.0788	0.0460	(-0.0143, 0.1719)	1.71	0.095	1.50
72	-0.0253	0.0460	(-0.1184, 0.0679)	-0.55	0.586	*
Blocks						
1	-0.0937	0.0958	(-0.2875, 0.1002)	-0.98	0.334	1.86
2	-0.0116	0.0958	(-0.2054, 0.1823)	-0.12	0.904	1.86
3	-0.0601	0.0958	(-0.2540, 0.1337)	-0.63	0.534	1.86
4	-0.0557	0.0958	(-0.2496, 0.1381)	-0.58	0.564	1.86
5	-0.1310	0.0958	(-0.3248, 0.0629)	-1.37	0.180	1.86
6	-0.0331	0.0958	(-0.2269, 0.1608)	-0.35	0.732	1.86
7	-0.0590	0.0958	(-0.2529, 0.1348)	-0.62	0.541	1.86
8	-0.0535	0.0958	(-0.2473, 0.1404)	-0.56	0.580	1.86
9	-0.0846	0.0958	(-0.2785, 0.1092)	-0.88	0.383	1.86
10	-0.1129	0.0958	(-0.3067, 0.0810)	-1.18	0.246	1.86
11	-0.0872	0.0958	(-0.2811, 0.1066)	-0.91	0.368	1.86
12	0.6671	0.0958	(0.4732, 0.8609)	6.96	0.000	1.86
13	0.0110	0.0958	(-0.1829, 0.2048)	0.11	0.909	1.86
14	0.1044	0.0958	(-0.0895, 0.2982)	1.09	0.283	*

Appendix E: Median Frequency

Table E1: Average MDF of VL of the treatment knee

Subject	Average MDF						
	Session 1 (nKT)	Session 2 (0 hrs)	Session 3 (24 hrs)	Session 4 (48 hrs)	Session 5 (72 hrs)	Session 6 (nKT_1)	Session 7 (nKT_2)
1	59.04	71.12	63.72	59.92	62.42	61.23	62.88
2	65.09	67.66	67.87	63.46	67.38	64.38	63.62
3	53.00	60.52	58.95	59.33	54.00	55.29	58.53
4	51.17	53.26	50.54	60.54	56.71	58.14	55.68
5	62.65	57.69	60.18	61.04	64.96	62.94	63.57
6	45.46	53.26	48.40	45.88	49.58	NA	NA
7	48.93	49.95	51.90	59.14	52.76	54.19	50.35
8	62.38	50.58	58.07	55.64	56.82	61.35	53.02
9	55.33	54.43	55.20	54.36	55.46	56.21	55.49
10	58.65	56.88	68.28	65.62	56.34	63.44	60.43
11	63.15	55.76	66.61	67.37	68.02	68.06	64.63
12	71.27	68.41	85.30	59.36	70.58	70.60	66.19
13	55.61	63.15	55.38	57.21	62.48	53.39	56.39
14	59.95	57.51	58.82	53.74	56.54	53.58	58.51

Table E2: Average MDF of VL the control knee

Subject	Average MDF						
	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7
1	70.19	64.41	70.55	63.27	58.99	58.41	69.38
2	60.09	56.94	66.01	63.16	62.88	62.86	64.53
3	60.49	60.98	60.77	59.34	59.33	62.21	63.00
4	55.65	53.79	55.56	58.81	60.16	59.93	58.82
5	55.86	62.21	59.25	62.37	61.74	66.74	64.47
6	47.70	46.53	46.52	46.54	46.40	NA	NA
7	55.00	46.77	50.29	52.01	52.41	49.41	57.28
8	63.49	58.10	63.26	54.03	56.84	60.18	57.02
9	53.22	51.34	50.47	51.00	50.75	53.71	52.11
10	65.10	55.28	59.40	55.55	60.31	58.68	50.04
11	59.69	67.97	61.54	74.50	67.92	66.52	64.34
12	69.48	74.49	75.60	71.60	73.21	76.17	73.21
13	59.86	53.44	53.17	57.42	60.25	57.72	53.61
14	63.32	60.91	61.06	59.88	62.26	63.43	62.72

Table E3 MDF of VM of the treatment knee

Subject	Average MDF						
	Session 1 (nKT)	Session 2 (0 hrs)	Session 3 (24 hrs)	Session 4 (48 hrs)	Session 5 (72 hrs)	Session 6 (nKT_1)	Session 7 (nKT_2)
1	57.37	57.20	64.43	58.40	59.41	58.69	57.95
2	64.33	63.71	59.88	59.58	60.16	63.80	62.30
3	60.43	61.57	61.21	57.92	55.56	61.09	65.99
4	51.59	52.44	50.49	52.29	54.27	56.92	60.14
5	62.30	62.12	60.65	59.92	62.15	67.70	64.37
6	46.47	49.73	49.36	49.69	52.07	NA	NA
7	47.69	48.54	45.43	51.98	48.95	51.88	49.13
8	62.46	56.70	58.48	57.26	55.84	59.08	52.02
9	54.11	53.99	54.30	53.30	55.63	55.94	54.81
10	66.71	65.98	65.54	69.47	57.80	61.82	67.68
11	51.01	54.00	56.39	62.20	61.42	58.81	60.24
12	72.57	68.47	75.98	67.56	71.20	70.15	65.49
13	51.63	55.47	52.98	54.34	54.46	53.80	54.46
14	61.70	53.05	65.33	60.60	68.60	63.26	70.02

Table E4: MDF of VM the control knee

Subject	Average MDF						
	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7
1	54.43	59.62	58.38	61.25	53.67	55.33	57.00
2	57.63	60.03	57.51	60.06	58.59	58.96	58.07
3	59.94	58.77	58.51	55.63	59.82	60.81	61.59
4	53.55	56.90	56.09	58.16	60.15	56.56	57.84
5	58.93	63.53	57.55	59.34	62.42	67.18	63.85
6	45.04	45.46	48.43	45.55	46.07	NA	NA
7	45.58	45.71	49.97	49.77	53.59	51.42	52.31
8	59.03	58.44	57.58	52.86	53.49	58.69	51.23
9	51.66	52.44	50.45	48.82	49.08	51.24	50.43
10	62.22	62.95	53.08	52.73	55.52	53.74	46.53
11	60.71	62.00	58.60	72.87	66.19	61.51	62.28
12	54.87	67.93	71.00	55.22	63.20	65.02	68.13
13	51.23	50.05	48.43	57.17	55.38	50.99	52.62
14	57.56	54.95	53.48	55.02	55.57	52.25	59.65

Table E5: Average MDF of RF of the treatment knee

Subject	Average MDF						
	Session 1 (nKT)	Session 2 (0 hrs)	Session 3 (24 hrs)	Session 4 (48 hrs)	Session 5 (72 hrs)	Session 6 (nKT_1)	Session 7 (nKT_2)
1	67.32	73.94	68.91	65.58	69.83	66.23	72.46
2	56.75	63.78	64.71	61.13	69.93	61.41	63.32
3	56.48	62.57	58.73	57.90	58.48	63.17	64.30
4	50.52	53.61	53.18	55.09	59.44	56.22	57.58
5	62.18	61.61	62.58	62.64	62.30	58.28	65.14
6	44.80	47.58	51.02	47.35	52.28	NA	NA
7	46.93	51.72	45.20	56.43	51.24	51.47	47.68
8	61.76	48.48	60.54	56.60	57.66	61.41	51.62
9	57.54	56.88	59.84	59.44	58.90	59.78	56.78
10	73.30	65.15	58.59	67.70	59.12	62.98	69.91
11	55.05	60.93	66.06	76.15	71.37	63.95	65.12
12	61.61	62.93	74.61	64.48	63.15	66.07	56.21
13	50.92	57.69	53.77	55.72	41.43	55.27	52.29
14	57.34	25.95	62.77	51.15	63.33	58.72	57.84

Table E6: Average MDF of RF the control knee

Subject	Average MDF						
	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7
1	70.58	70.55	71.64	70.84	69.90	69.49	70.25
2	69.92	66.99	61.46	64.79	63.86	64.86	67.56
3	62.89	60.42	61.30	59.20	65.45	63.72	63.32
4	55.72	46.38	65.58	58.64	60.52	58.35	56.41
5	61.05	65.46	60.86	63.16	66.09	68.89	65.96
6	45.91	46.76	47.52	48.11	50.40	NA	NA
7	50.37	42.49	49.15	48.18	52.96	52.88	54.90
8	54.04	59.15	57.63	54.72	57.93	60.53	47.21
9	56.02	53.15	53.22	53.00	53.72	54.32	54.47
10	63.49	54.55	56.90	57.46	63.55	60.69	54.64
11	57.17	61.06	61.60	67.34	73.27	67.30	68.05
12	70.60	71.00	72.10	58.26	66.48	73.59	68.26
13	57.67	51.70	52.78	59.66	57.48	55.56	51.76
14	61.07	55.09	54.69	54.58	59.16	55.84	65.56

Table E7: Paired T-test results for MDF of VL in the treatment knee and control knee

Paired T-Test and CI: AvgMDF_VL2, AvgMDF_VL1

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
AvgMDF_VL2	14	58.58	6.71	1.79
AvgMDF_VL1	14	57.98	6.92	1.85

Estimation for Paired Difference

Mean	StDev	SE Mean	95% Lower Bound for μ_difference
0.61	6.58	1.76	-2.51

μ_difference: mean of (AvgMDF_VL2 - AvgMDF_VL1)

Test

Null hypothesis H₀: μ_difference = 0

Alternative hypothesis H₁: μ_difference > 0

T-Value	P-Value
0.35	0.368

Table E8: Paired T-test results for MDF of VM in the treatment knee

Paired T-Test and CI: AvgMDF_VM2, AvgMDF_VM1

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
AvgMDF_VM2	14	57.35	6.10	1.63
AvgMDF_VM1	14	57.88	7.70	2.06

Estimation for Paired Difference

Mean	StDev	SE Mean	95% Lower Bound for μ_difference
-0.529	3.495	0.934	-2.184

μ_difference: mean of (AvgMDF_VM2 - AvgMDF_VM1)

Test

Null hypothesis H₀: μ_difference = 0

Alternative hypothesis H₁: μ_difference > 0

T-Value	P-Value
-0.57	0.710

Table E9: Paired T-test results for MDF of RF in the treatment knee

Paired T-Test and CI: AvgMDF_RF2, AvgMDF_RF1

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
AvgMDF_RF2	13	58.99	7.37	2.04
AvgMDF_RF1	13	57.32	8.04	2.23

Estimation for Paired Difference

Mean	StDev	SE Mean	95% Lower Bound for μ_difference
1.67	6.19	1.72	-1.39

μ_difference: mean of (AvgMDF_RF2 - AvgMDF_RF1)

Test

Null hypothesis	H_0: μ_difference = 0
Alternative hypothesis	H_1: μ_difference > 0

T-Value	P-Value
0.97	0.175

Table E10: General Linear ANOVA results for the effect of duration on MDF of VL in the treatment knee

General Linear Model: Diff AvgMDF_VL versus Duration, Blocks

Method

Factor coding	(-1, 0, +1)

Factor Information

Factor	Type	Levels	Values
Duration	Fixed	4	0, 24, 48, 72
Blocks	Fixed	14	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14

Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Duration	3	37.68	2.35%	37.68	12.56	0.56	0.647
Blocks	13	688.33	42.87%	688.33	52.95	2.35	0.020
Error	39	879.56	54.78%	879.56	22.55		
Total	55	1605.57	100.00%				

Model Summary

S	R-sq	R-sq(adj)	PRESS	R-sq(pred)	AICc	BIC
4.74899	45.22%	22.74%	1813.48	0.00%	367.64	385.61

Table E11: General Linear ANOVA results for the effect of duration on MDF of VM in treatment knee

General Linear Model: Diff AvgMDF_VM versus Duration, Blocks

Method

Factor coding	(-1, 0, +1)

Factor Information

Factor	Type	Levels	Values
Duration	Fixed	4	0, 24, 48, 72
Blocks	Fixed	14	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14

Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Duration	3	12.56	1.31%	12.56	4.185	0.41	0.748
Blocks	13	543.73	56.91%	543.73	41.825	4.09	0.000
Error	39	399.22	41.78%	399.22	10.236		
Total	55	955.51	100.00%				

Model Summary

S	R-sq	R-sq(adj)	PRESS	R-sq(pred)	AICc	BIC
3.19944	58.22%	41.08%	823.110	13.86%	323.40	341.37

Table X: General Linear ANOVA results for the effect of duration on MDF of RF in the treatment knee

General Linear Model: Diff Avg MDF_RF versus Duration, Blocks

Method

Factor coding	(-1, 0, +1)
Rows unused	1

Factor Information

Factor	Type	Levels	Values
Duration	Fixed	4	0, 24, 48, 72
Blocks	Fixed	14	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14

Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Duration	3	8.78	0.35%	9.84	3.281	0.15	0.927
Blocks	13	1706.89	67.52%	1706.89	131.299	6.14	0.000
Error	38	812.39	32.13%	812.39	21.379		
Total	54	2528.07	100.00%				

Model Summary

S	R-sq	R-sq(adj)	PRESS	R-sq(pred)	AICc	BIC
4.62371	67.87%	54.33%	1731.76	31.50%	359.18	376.31

Table X: General Linear ANOVA results for the effect of duration on MDF of VL in control knee

General Linear Model: Difference in MDF_VL versus Duration, Blocks

Method

Factor coding	(-1, 0, +1)
Rows unused	1

Factor Information

Factor	Type	Levels	Values
Duration	Fixed	4	24, 48, 72, 96
Blocks	Fixed	14	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14

Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Duration	3	6.21	0.44%	15.20	5.066	0.57	0.640
Blocks	13	1062.48	75.47%	1062.48	81.729	9.16	0.000
Error	38	339.06	24.09%	339.06	8.923		
Total	54	1407.75	100.00%				

Model Summary

S	R-sq	R-sq(adj)	PRESS	R-sq(pred)	AICc	BIC
2.98708	75.91%	65.77%	707.191	49.76%	311.12	328.25

Table X: General Linear ANOVA results for the effect of duration on MDF of VM in the control knee

General Linear Model: Difference in MDF_VM versus Duration, Blocks

Method

Factor coding	(-1, 0, +1)
Rows unused	1

Factor Information

Factor	Type	Levels	Values
Duration	Fixed	4	24, 48, 72, 96
Blocks	Fixed	14	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14

Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Duration	3	17.59	1.29%	7.794	2.598	0.22	0.884
Blocks	13	894.70	65.49%	894.704	68.823	5.76	0.000
Error	38	453.96	33.23%	453.961	11.946		
Total	54	1366.25	100.00%				

Model Summary

S	R-sq	R-sq(adj)	PRESS	R-sq(pred)	AICc	BIC
3.45635	66.77%	52.78%	940.126	31.19%	327.17	344.30

Table X: General Linear ANOVA results for the effect of duration on EMG-MDF of RF in the control knee

General Linear Model: Difference in MDF_RF versus Duration, Blocks

Method

Factor coding	(-1, 0, +1)
Rows unused	1

Factor Information

Factor	Type	Levels	Values
Duration	Fixed	4	24, 48, 72, 96
Blocks	Fixed	14	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14

Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Duration	3	100.6	6.94%	111.2	37.06	2.71	0.059
Blocks	13	827.8	57.13%	827.8	63.67	4.65	0.000
Error	38	520.4	35.92%	520.4	13.70		
Total	54	1448.8	100.00%				

Model Summary

S	R-sq	R-sq(adj)	PRESS	R-sq(pred)	AICc	BIC
3.70077	64.08%	48.95%	1084.06	25.18%	334.69	351.82

Appendix F: Root Mean Square

Table F1: Normalized average RMS of VL the treatment knee

Subject	RMS						
	Session 1 (nKT)	Session 2 (0 hrs)	Session 3 (24 hrs)	Session 4 (48 hrs)	Session 5 (72 hrs)	Session 6 (nKT_1)	Session 7 (nKT_2)
1	0.19	0.20	0.17	0.18	0.17	0.13	0.15
2	0.25	0.22	0.23	0.21	0.22	0.21	0.17
3	0.19	0.19	0.20	0.19	0.22	0.18	0.19
4	0.19	0.18	0.15	0.15	0.16	0.13	0.14
5	0.17	0.19	0.19	0.17	0.15	0.15	0.18
6	0.20	0.15	0.18	0.20	0.16	N/A	N/A
7	0.17	0.18	0.20	0.18	0.16	0.21	0.20
8	0.19	0.16	0.19	0.22	0.18	0.19	0.21
9	0.21	0.21	0.20	0.15	0.19	0.18	0.22
10	0.34	0.27	0.27	0.31	0.32	0.27	0.31
11	0.25	0.25	0.20	0.21	0.23	0.21	0.20
12	0.26	0.25	0.31	0.26	0.23	0.26	0.30
13	0.24	0.28	0.23	0.21	0.24	0.22	0.23
14	0.20	0.23	0.24	0.27	0.26	0.23	0.25

Table F2: Normalized average RMS of VL the control knee

Subject	RMS						
	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7
1	0.21	0.14	0.12	0.17	0.13	0.14	0.17
2	0.17	0.26	0.24	0.21	0.22	0.20	0.20
3	0.20	0.19	0.19	0.17	0.19	0.19	0.19
4	0.21	0.17	0.16	0.15	0.16	0.13	0.15
5	0.20	0.19	0.20	0.19	0.18	0.16	0.16
6	0.21	0.21	0.17	0.17	0.15	N/A	N/A
7	0.17	0.18	0.20	0.18	0.18	0.08	0.21
8	0.24	0.25	0.21	0.20	0.19	0.19	0.16
9	0.21	0.23	0.21	0.20	0.20	0.21	0.20
10	0.31	0.30	0.36	0.23	0.28	0.25	0.22
11	0.25	0.25	0.24	0.23	0.26	0.25	0.23
12	0.23	0.25	0.23	0.30	0.25	0.27	0.28
13	0.22	0.24	0.22	0.23	0.24	0.25	0.24
14	0.29	0.26	0.17	0.27	0.22	0.30	0.26

Table F3 Normalized average RMS of VM of the treatment knee

Subject	RMS						
	Session 1 (nKT)	Session 2 (0 hrs)	Session 3 (24 hrs)	Session 4 (48 hrs)	Session 5 (72 hrs)	Session 6 (nKT_1)	Session 7 (nKT_2)
1	0.24	0.16	0.17	0.16	0.17	0.13	0.16
2	0.22	0.19	0.20	0.19	0.19	0.17	0.17
3	0.23	0.22	0.19	0.20	0.21	0.21	0.20
4	0.22	0.17	0.17	0.16	0.17	0.15	0.15
5	0.19	0.19	0.17	0.19	0.17	0.20	0.18
6	0.20	0.21	0.21	0.21	0.17	N/A	N/A
7	0.21	0.15	0.17	0.16	0.14	0.17	0.17
8	0.18	0.18	0.16	0.22	0.16	0.17	0.21
9	0.24	0.23	0.20	0.17	0.17	0.20	0.18
10	0.32	0.37	0.30	0.32	0.38	0.32	0.31
11	0.27	0.25	0.27	0.23	0.22	0.24	0.19
12	0.27	0.23	0.26	0.26	0.26	0.27	0.30
13	0.25	0.25	0.21	0.19	0.20	0.16	0.12
14	0.19	0.21	0.25	0.24	0.25	0.27	0.28

Table F4: Normalized average RMS of VM the control knee

Subject	RMS						
	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7
1	0.18	0.17	0.17	0.19	0.15	0.17	0.18
2	0.22	0.26	0.21	0.28	0.22	0.21	0.16
3	0.20	0.20	0.19	0.20	0.21	0.16	0.21
4	0.18	0.14	0.13	0.14	0.16	0.13	0.13
5	0.20	0.18	0.19	0.19	0.18	0.17	0.15
6	0.24	0.18	0.20	0.20	0.20	N/A	N/A
7	0.18	0.16	0.16	0.15	0.13	0.13	0.13
8	0.22	0.18	0.18	0.22	0.19	0.18	0.18
9	0.21	0.19	0.19	0.17	0.20	0.22	0.21
10	0.30	0.39	0.27	0.29	0.28	0.27	0.26
11	0.25	0.25	0.27	0.24	0.22	0.21	0.22
12	0.28	0.25	0.23	0.25	0.24	0.22	0.26
13	0.25	0.22	0.22	0.21	0.24	0.22	0.21
14	0.25	0.25	0.23	0.26	0.27	0.23	0.26

Table F5: Normalized average RMS of RF of the treatment knee

Subject	RMS						
	Session 1 (nKT)	Session 2 (0 hrs)	Session 3 (24 hrs)	Session 4 (48 hrs)	Session 5 (72 hrs)	Session 6 (nKT_1)	Session 7 (nKT_2)
1	0.20	0.18	0.18	0.13	0.17	0.14	0.17
2	0.20	0.23	0.25	0.22	0.23	0.20	0.19
3	0.17	0.17	0.21	0.22	0.16	0.18	0.19
4	0.17	0.17	0.16	0.17	0.16	0.12	0.17
5	0.15	0.16	0.14	0.12	0.13	0.15	0.14
6	0.19	0.11	0.15	0.18	0.15	N/A	N/A
7	0.15	0.16	0.17	0.17	0.16	0.16	0.18
8	0.18	0.21	0.17	0.19	0.19	0.17	0.20
9	0.18	0.18	0.18	0.16	0.16	0.17	0.16
10	0.36	0.34	0.27	0.35	0.31	0.32	0.29
11	0.15	0.27	0.25	0.21	0.22	0.25	0.22
12	0.23	0.21	0.28	0.30	0.28	0.23	0.28
13	0.25	0.27	0.23	0.22	0.20	0.21	0.20
14	0.22	0.19	0.21	0.23	0.22	0.20	0.24

Table F6: Normalized average RMS of RF the control knee

Subject	RMS						
	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7
1	0.18	0.19	0.19	0.17	0.17	0.17	0.16
2	0.20	0.23	0.21	0.20	0.19	0.19	0.18
3	0.21	0.22	0.21	0.17	0.21	0.17	0.21
4	0.17	0.18	0.14	0.13	0.16	0.12	0.13
5	0.17	0.15	0.18	0.16	0.14	0.15	0.14
6	0.21	0.18	0.20	0.19	0.17	N/A	N/A
7	0.13	0.16	0.17	0.14	0.16	0.16	0.18
8	0.17	0.19	0.15	0.18	0.16	0.17	0.18
9	0.20	0.20	0.17	0.17	0.19	0.22	0.20
10	0.28	0.33	0.24	0.27	0.27	0.27	0.23
11	0.23	0.27	0.26	0.23	0.23	0.24	0.24
12	0.22	0.27	0.21	0.26	0.26	0.26	0.28
13	0.26	0.23	0.25	0.12	0.22	0.25	0.22
14	0.21	0.20	0.18	0.25	0.24	0.22	0.24

Table F7: Paired T-test results for normalized average RMS of VL in the treatment knee

Paired T-Test and CI: RMS_VL_Sess.2, RMS_VL_Sess.1

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
RMS_VL_Sess.2	14	0.000832	0.001007	0.000269
RMS_VL_Sess.1	14	0.000916	0.000995	0.000266

Estimation for Paired Difference

Mean	StDev	SE Mean	95% Upper Bound for μ_difference
-0.000084	0.000281	0.000075	0.000049

μ_difference: population mean of (RMS_VL_Sess.2 - RMS_VL_Sess.1)

Test

Null hypothesis	H_0: μ_difference = 0
Alternative hypothesis	H_1: μ_difference < 0

T-Value	P-Value
-1.11	0.143

Table F8: Paired T-test results for normalized average RMS of VM in the treatment knee

TREATMENT _PAIR-T

Paired T-Test and CI: AvgRMS_VM_2, AvgRMS_VM_1

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
AvgRMS_VM_2	14	0.2149	0.0538	0.0144
AvgRMS_VM_1	14	0.2308	0.0387	0.0104

Estimation for Paired Difference

Mean	StDev	SE Mean	95% Upper Bound for μ_difference
-0.01586	0.03236	0.00865	-0.00055

μ_difference: mean of (AvgRMS_VM_2 - AvgRMS_VM_1)

Test

Null hypothesis	H_0: μ_difference = 0
Alternative hypothesis	H_1: μ_difference < 0

T-Value	P-Value
-1.83	0.045

Table F9: Paired T-test results for normalized average RMS of RF in the treatment knee

TREATMENT _PAIR-T

Paired T-Test and CI: AvgRMS_RF_2, AvgRMS_RF_1

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
AvgRMS_RF_2	14	0.2020	0.0579	0.0155
AvgRMS_RF_1	14	0.1993	0.0561	0.0150

Estimation for Paired Difference

Mean	StDev	SE Mean	95% Upper Bound for μ_difference
0.0027	0.0443	0.0118	0.0237

μ_difference: mean of (AvgRMS_RF_2 - AvgRMS_RF_1)

Test

Null hypothesis H_0: μ_difference = 0

Alternative hypothesis H_1: μ_difference < 0

T-Value	P-Value
0.23	0.588

Table F10: Paired T-test results for normalized average rate RMS of VL in the treatment knee

TREATMENT _PAIR-T

Paired T-Test and CI: AvgRateRMS_VL2, AvgRateRMS_VL1

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
AvgRateRMS_VL2	14	0.003929	0.002833	0.000757
AvgRateRMS_VL1	14	0.004201	0.003296	0.000881

Estimation for Paired Difference

Mean	StDev	SE Mean	95% Upper Bound for μ_difference
-0.000271	0.001108	0.000296	0.000253

μ_difference: mean of (AvgRateRMS_VL2 - AvgRateRMS_VL1)

Test

Null hypothesis H_0: μ_difference = 0

Alternative hypothesis H_1: μ_difference < 0

T-Value	P-Value
-0.92	0.188

Table F11: Paired T-test results for normalized average rate RMS of VM in the treatment knee

TREATMENT _PAIR-T

Paired T-Test and CI: AvgRateRMS_VM2, AvgRateRMS_VM1

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
AvgRateRMS_VM2	14	0.004146	0.003508	0.000937
AvgRateRMS_VM1	14	0.004328	0.003162	0.000845

Estimation for Paired Difference

Mean	StDev	SE Mean	95% Upper Bound for μ_difference
-0.000182	0.000646	0.000173	0.000124

μ_difference: mean of (AvgRateRMS_VM2 - AvgRateRMS_VM1)

Test

Null hypothesis H₀: μ_difference = 0

Alternative hypothesis H₁: μ_difference < 0

T-Value	P-Value
-1.05	0.156

Table F12: Paired T-test results for normalized average rate RMS of RF in the treatment knee

TREATMENT _PAIR-T

Paired T-Test and CI: AvgRateRMS_RF2, AvgRateRMS_RF1

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
AvgRateRMS_RF2	14	0.003987	0.003424	0.000915
AvgRateRMS_RF1	14	0.003870	0.003412	0.000912

Estimation for Paired Difference

Mean	StDev	SE Mean	95% Upper Bound for μ_difference
0.000118	0.001285	0.000343	0.000726

μ_difference: mean of (AvgRateRMS_RF2 - AvgRateRMS_RF1)

Test

Null hypothesis H_0: μ_difference = 0

Alternative hypothesis H_1: μ_difference < 0

T-Value	P-Value
0.34	0.631

Table F13: General Linear ANOVA results for the effect of duration on average RMS of VL in the treatment knee

General Linear Model: Diff AvgRMS_VL versus Duration, Blocks

Method

Factor coding	(-1, 0, +1)

Factor Information

Factor	Type	Levels	Values
Duration	Fixed	4	0, 24, 48, 72
Blocks	Fixed	14	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14

Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Duration	3	0.000212	0.43%	0.000212	0.000071	0.15	0.932
Blocks	13	0.030518	61.47%	0.030518	0.002348	4.84	0.000
Error	39	0.018913	38.10%	0.018913	0.000485		
Total	55	0.049643	100.00%				

Model Summary

S	R-sq	R-sq(adj)	PRESS	R-sq(pred)	AICc	BIC
0.0220215	61.90%	46.27%	0.0389948	21.45%	-234.21	-216.25

Table F14: General Linear ANOVA results for the effect of duration on RMS of VM in the treatment knee

General Linear Model: Diff AvgRMS_VM versus Duration, Blocks

Method

Factor coding	(-1, 0, +1)
Rows unused	3

Factor Information

Factor	Type	Levels	Values
Duration	Fixed	4	0, 24, 48, 72
Blocks	Fixed	14	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14

Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Duration	3	0.003765	7.99%	0.001879	0.000626	1.87	0.152
Blocks	13	0.031310	66.44%	0.031310	0.002408	7.19	0.000
Error	36	0.012052	25.57%	0.012052	0.000335		
Total	52	0.047127	100.00%				

Model Summary

S	R-sq	R-sq(adj)	PRESS	R-sq(pred)	AICc	BIC
0.0182970	74.43%	63.06%	0.0276324	41.37%	-238.08	-222.73

Table F15: General Linear ANOVA results for the effect of duration on RMS of RF in the treatment knee

General Linear Model: Diff AvgRMS_RF versus Duration, Blocks

Method

Factor coding	(-1, 0, +1)
Rows unused	2

Factor Information

Factor	Type	Levels	Values
Duration	Fixed	4	0, 24, 48, 72
Blocks	Fixed	14	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14

Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Duration	3	0.001261	1.99%	0.000698	0.000233	0.43	0.730
Blocks	13	0.042239	66.70%	0.042239	0.003249	6.06	0.000
Error	37	0.019823	31.30%	0.019823	0.000536		
Total	53	0.063323	100.00%				

Model Summary

S	R-sq	R-sq(adj)	PRESS	R-sq(pred)	AICc	BIC
0.0231464	68.70%	55.16%	0.0418910	33.85%	-218.35	-202.09

Table F16: General Linear ANOVA results for the effect of duration on RMS of VL in the control knee

General Linear Model: Diff AvgRMS_VL versus Duration, Blocks

Factor coding	(-1, 0, +1)
Rows unused	1

Factor Information

Factor	Type	Levels	Values
Duration	Fixed	4	24, 48, 72, 96
Blocks	Fixed	14	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14

Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Duration	3	0.003145	3.41%	0.003189	0.001063	1.67	0.189
Blocks	13	0.064988	70.43%	0.064988	0.004999	7.87	0.000
Error	38	0.024135	26.16%	0.024135	0.000635		
Total	54	0.092269	100.00%				

Model Summary

S	R-sq	R-sq(adj)	PRESS	R-sq(pred)	AICc	BIC
0.0252020	73.84%	62.83%	0.0543368	41.11%	-214.14	-197.01

Table F17: General Linear ANOVA results for the effect of duration on RMS of VM in the control knee

General Linear Model: Diff AvgRMS_VM versus Duration, Blocks

Method

Factor coding	(-1, 0, +1)
Rows unused	3

Factor Information

Factor	Type	Levels	Values
Duration	Fixed	4	24, 48, 72, 96
Blocks	Fixed	14	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14

Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Duration	3	0.000200	1.00%	0.000260	0.000087	0.48	0.695
Blocks	13	0.013256	66.66%	0.013256	0.001020	5.71	0.000
Error	36	0.006429	32.33%	0.006429	0.000179		
Total	52	0.019885	100.00%				

Model Summary

S	R-sq	R-sq(adj)	PRESS	R-sq(pred)	AICc	BIC
0.0133633	67.67%	53.30%	0.0134320	32.45%	-271.39	-256.04

Table F18: General Linear ANOVA results for the effect of duration on RMS of RF in the control knee

General Linear Model: Diff AvgRMS_RF versus Duration, Blocks

Method

Factor coding	(-1, 0, +1)
Rows unused	2

Factor Information

Factor	Type	Levels	Values
Duration	Fixed	4	24, 48, 72, 96
Blocks	Fixed	14	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14

Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Duration	3	0.002049	6.19%	0.001865	0.000622	1.72	0.180
Blocks	13	0.017645	53.32%	0.017645	0.001357	3.75	0.001
Error	37	0.013397	40.48%	0.013397	0.000362		
Total	53	0.033091	100.00%				

Model Summary

S	R-sq	R-sq(adj)	PRESS	R-sq(pred)	AICc	BIC
0.0190282	59.52%	42.01%	0.0283755	14.25%	-239.51	-223.25

Appendix G: MANCOVA

Table G1: MANVOA result

MANOVA TREATMENT

General Linear Model: Difference_rSO2_VL, Difference_rSO2_VM, Difference in RMS_VL, % Change in TTM of VM, % Chan...

MANOVA Tests for Duration

Criterion	Test Statistic	Approx F	DF Num	DF Denom	P
Wilks'	0.82845	0.413	18	107	0.983
Lawley-Hotelling	0.19717	0.402	18	110	0.985
Pillai's	0.17978	0.425	18	120	0.980
Roy's	0.10963				

s = 3   m = 1   n = 18

Appendix H: Cycle Rate

Table H1: Cycle rate of the treatment knee

Subject	Cycle rate (repetition/sec)						
	Session 1 (nKT)	Session 2 (0 hrs)	Session 3 (24 hrs)	Session 4 (48 hrs)	Session 5 (72 hrs)	Session 6 (nKT_1)	Session 7 (nKT_2)
1	0.51	0.54	0.53	0.52	0.52	0.53	0.66
2	0.97	1.00	0.95	1.00	0.96	0.96	0.94
3	0.83	0.86	0.89	0.87	0.86	0.90	0.88
4	1.06	0.74	0.78	0.75	0.78	0.80	0.69
5	0.79	0.85	0.77	0.81	0.82	0.86	0.79
6	0.70	0.63	0.67	0.61	0.60	0.77	0.78
7	0.81	0.82	0.84	0.89	0.86	0.93	0.89
8	0.80	0.84	0.84	0.92	0.88	0.86	0.88
9	0.76	0.73	0.75	0.69	0.82	0.82	0.94
10	0.80	0.88	0.95	0.97	1.00	1.00	1.09
11	0.80	0.88	0.88	0.94	0.97	0.91	0.91
12	0.96	0.96	1.21	1.30	1.26	1.17	1.19
13	0.98	1.05	0.96	0.98	0.95	0.88	0.89
14	0.77	0.94	0.89	1.00	0.95	1.02	0.98

Table H2: Cycle rate of the control knee

Subject	Cycle rate (repetition/sec)						
	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7
1	0.48	0.55	0.50	0.50	0.52	0.54	0.58
2	0.97	1.00	0.97	0.98	0.96	0.96	0.94
3	0.77	0.65	0.85	0.82	0.83	0.85	0.81
4	0.81	0.76	0.82	0.81	0.84	0.79	0.77
5	0.86	0.81	0.82	0.83	0.84	0.84	0.85
6	0.58	0.62	0.63	0.62	0.58	0.65	0.65
7	0.81	0.84	0.86	0.85	0.88	0.85	0.89
8	0.80	0.86	0.84	0.87	0.84	0.90	0.87
9	0.83	0.78	0.83	0.79	0.77	0.89	0.94
10	0.87	0.64	0.79	0.81	0.89	0.83	0.97
11	0.94	0.94	0.93	0.90	1.13	0.92	0.91
12	0.96	1.00	1.00	1.21	1.21	1.24	1.18
13	0.87	0.83	0.88	0.90	0.87	0.91	0.84
14	0.90	0.87	0.85	1.02	1.13	0.95	0.96

Table H3: Paired T-test results for cycle rate in the treatment knee

Paired T-Test and CI: C_Rate_2, C_Rate_1

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
C_Rate_2	14	0.8375	0.1380	0.0369
C_Rate_1	14	0.8247	0.1378	0.0368

Estimation for Paired Difference

Mean	StDev	SE Mean	95% CI for μ_difference
0.0128	0.1108	0.0296	(-0.0512, 0.0768)

μ_difference: mean of (C_Rate_2 - C_Rate_1)

Test

Null hypothesis H₀: μ_difference = 0

Alternative hypothesis H₁: μ_difference ≠ 0

T-Value	P-Value
0.43	0.672

Table H4: Paired T-test results for cycle rate in the control knee

Paired T-Test and CI: C_Rate_2, C_Rate_1

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
C_Rate_2	14	0.7956	0.1404	0.0375
C_Rate_1	14	0.8178	0.1381	0.0369

Estimation for Paired Difference

Mean	StDev	SE Mean	95% CI for μ_difference
-0.0222	0.0814	0.0218	(-0.0693, 0.0248)

μ_difference: mean of (C_Rate_2 - C_Rate_1)

Test

Null hypothesis H₀: μ_difference = 0

Alternative hypothesis H₁: μ_difference ≠ 0

T-Value	P-Value
-1.02	0.325

Table H5: General Linear ANOVA results for the effect of duration on cycle rate in the treatment knee

General Linear Model: Cycle_Rate versus Duration, Blocks

Method

Factor coding (-1, 0, +1)

Factor Information

Factor	Type	Levels	Values
Duration	Fixed	4	0, 24, 48, 72
Blocks	Fixed	14	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Duration	3	0.01611	0.005370	1.52	0.225
Blocks	13	0.94617	0.072782	20.57	0.000
Error	39	0.13800	0.003538		
Total	55	1.10028			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0594852	87.46%	82.31%	74.14%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	0.04644	0.00795	5.84	0.000	
Duration					
0	-0.0233	0.0138	-1.69	0.098	1.50
24	-0.0090	0.0138	-0.65	0.518	1.50
48	0.0175	0.0138	1.27	0.211	1.50
Blocks					
1	-0.0021	0.0287	-0.07	0.942	1.86
2	-0.0371	0.0287	-1.30	0.203	1.86
3	-0.0062	0.0287	-0.22	0.829	1.86
4	-0.3268	0.0287	-11.40	0.000	1.86
5	-0.0228	0.0287	-0.80	0.430	1.86
6	-0.1493	0.0287	-5.21	0.000	1.86
7	0.0034	0.0287	0.12	0.907	1.86
8	0.0394	0.0287	1.37	0.177	1.86
9	-0.0648	0.0287	-2.26	0.029	1.86
10	0.1425	0.0287	4.97	0.000	1.86
11	0.0967	0.0287	3.37	0.002	1.86
12	0.1853	0.0287	6.46	0.000	1.86
13	-0.0422	0.0287	-1.47	0.149	1.86

Table H2: General Linear ANOVA results for the effect of duration on cycle rate in the control knee

General Linear Model: C_Rate versus Duration, Blocks

Method

Factor coding	(-1, 0, +1)
Rows unused	4

Factor Information

Factor	Type	Levels	Values
Duration	Fixed	4	24, 48, 72, 96
Blocks	Fixed	14	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Duration	3	0.005545	0.001848	0.69	0.562
Blocks	13	0.098660	0.007589	2.85	0.007
Error	34	0.090575	0.002664		
Total	50	0.193693			

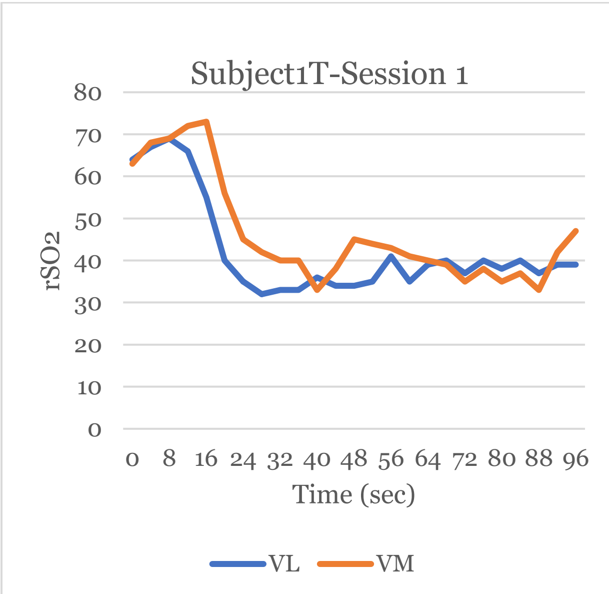
Model Summary

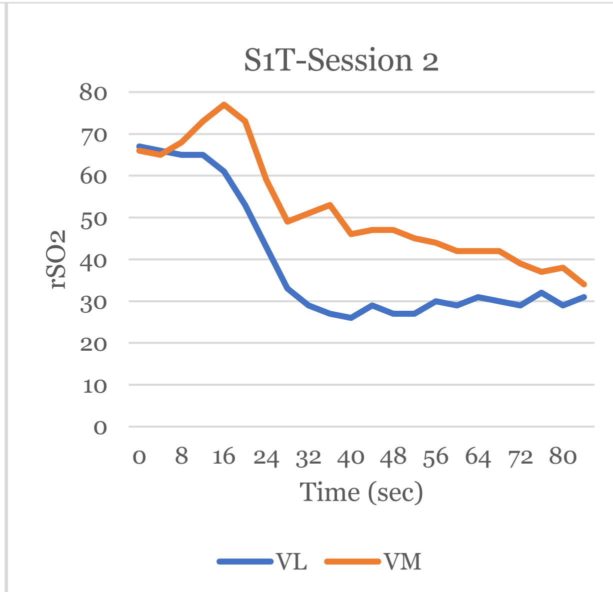
S	R-sq	R-sq(adj)	R-sq(pred)
0.0516137	53.24%	31.23%	0.00%

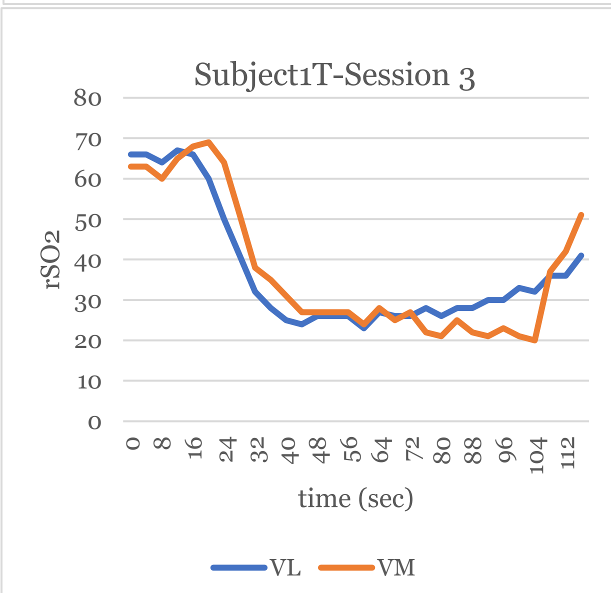
Coefficients

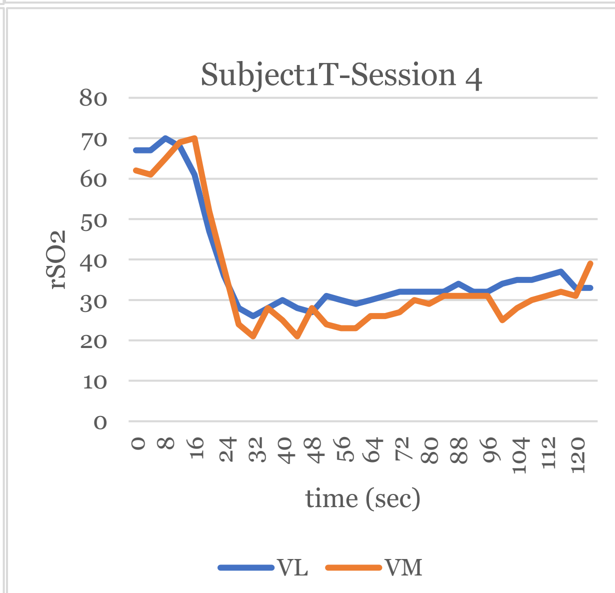
Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	0.02252	0.00740	3.04	0.004	
Duration					
24	-0.0126	0.0132	-0.96	0.345	1.56
48	-0.0065	0.0122	-0.53	0.601	1.46
72	0.0024	0.0126	0.19	0.853	1.48
Blocks					
1	0.0634	0.0250	2.53	0.016	1.64
2	-0.0201	0.0250	-0.80	0.428	1.64
3	0.0515	0.0289	1.79	0.083	1.88
4	-0.0221	0.0250	-0.89	0.382	1.64
5	-0.0619	0.0250	-2.48	0.018	1.64
6	0.0341	0.0250	1.36	0.182	1.64
7	0.0378	0.0250	1.51	0.140	1.64
8	0.0381	0.0250	1.52	0.137	1.64
9	-0.0711	0.0250	-2.84	0.008	1.64
10	-0.0718	0.0289	-2.49	0.018	1.88
11	0.0128	0.0250	0.51	0.613	1.64
12	0.0315	0.0353	0.89	0.379	2.33
13	-0.0186	0.0250	-0.74	0.463	1.64

Appendix I: Regional Muscle Oxygenation Saturation









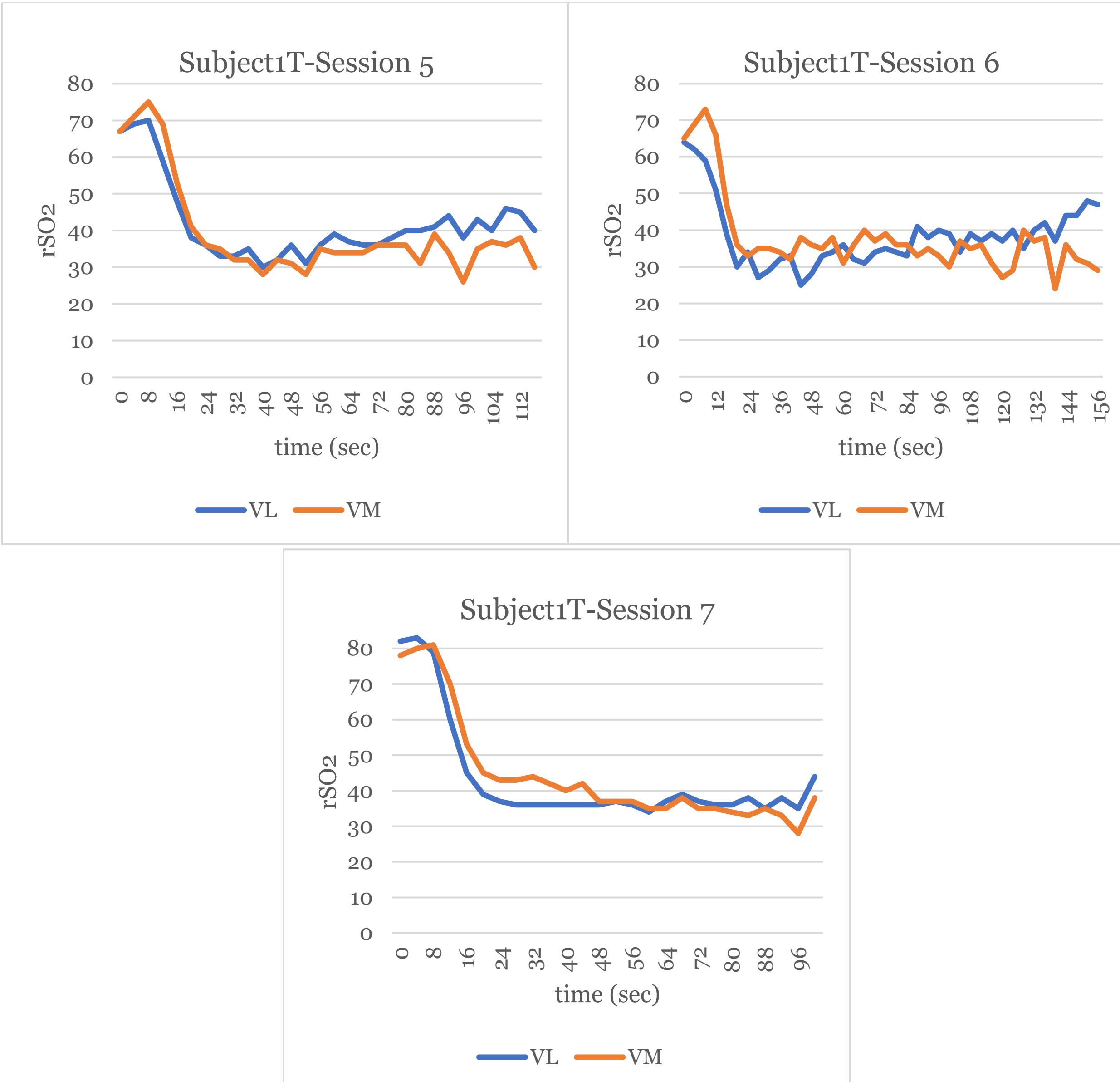
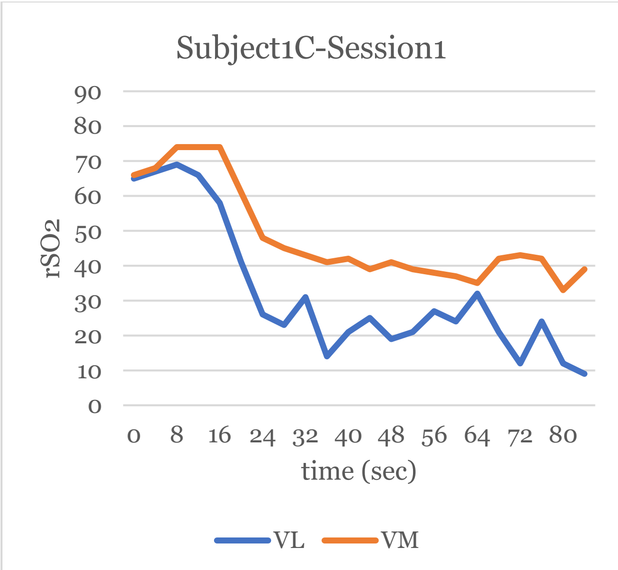
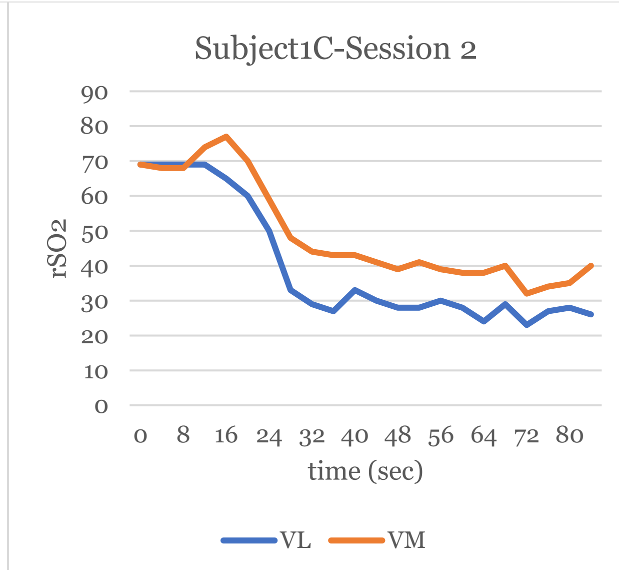
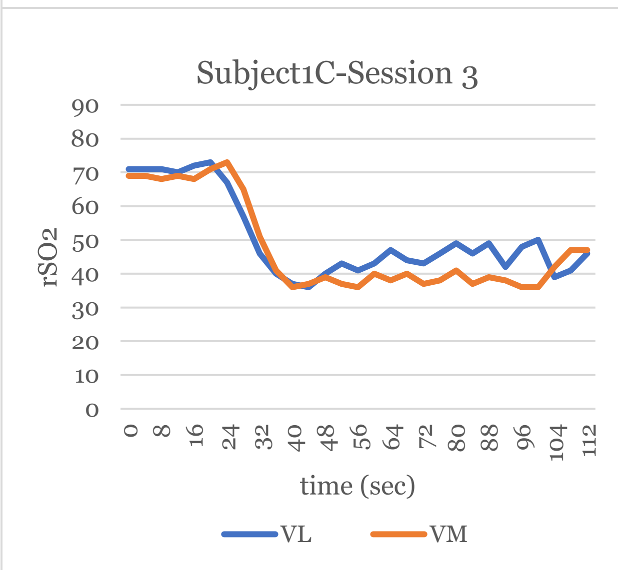
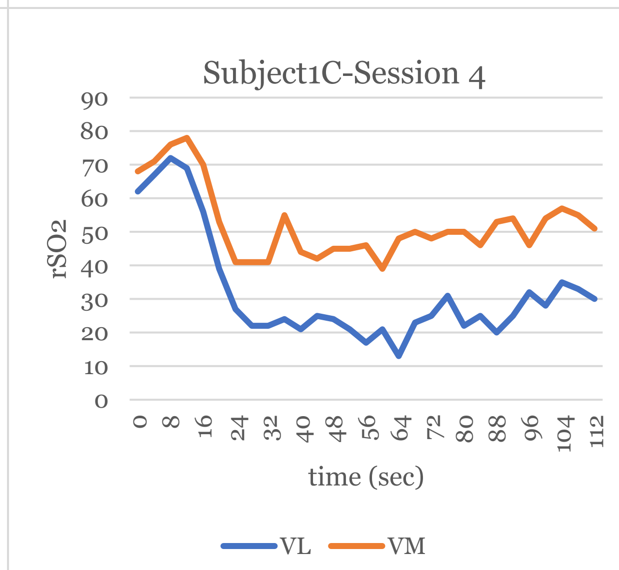


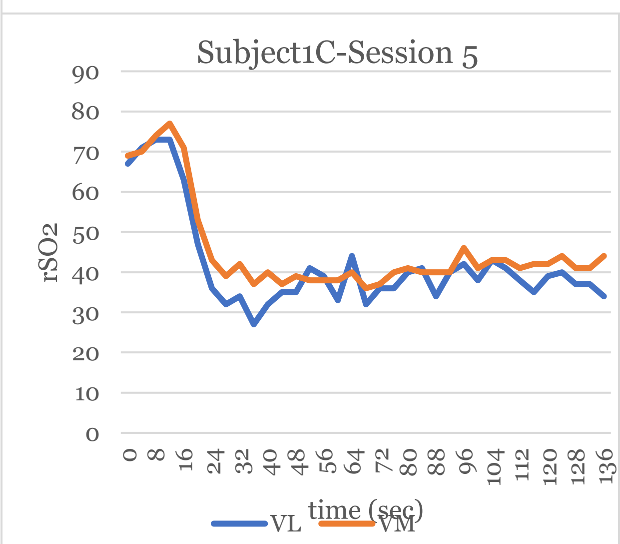
Figure I1: Regional muscle oxygenation saturation in the treatment knee of subject 1 across 7 sessions

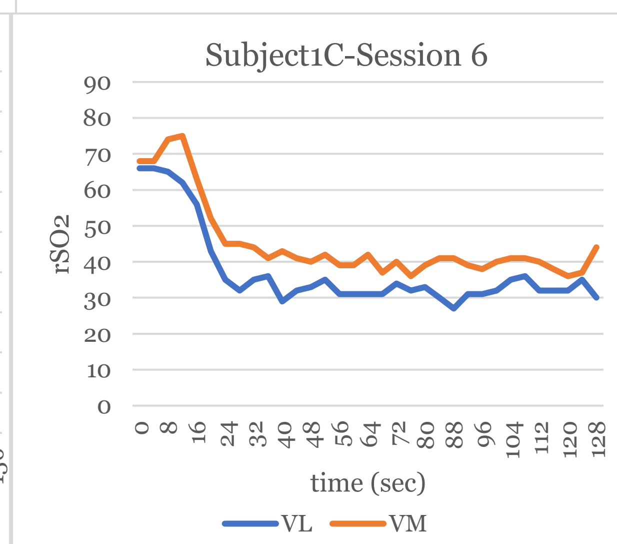

Subject1C-Session1
rSO2
90 80 70 60 50 40 30 20 10 0
0 8 16 24 32 40 48 56 64 72 80
time (sec)
VL
VM


Subject1C-Session 2
rSO2
90 80 70 60 50 40 30 20 10 0
0 8 16 24 32 40 48 56 64 72 80
time (sec)
VL
VM


Subject1C-Session 3
rSO2
90 80 70 60 50 40 30 20 10 0
0 8 16 24 32 40 48 56 64 72 80 88 96 104 112
time (sec)
VL
VM


Subject1C-Session 4
rSO2
90 80 70 60 50 40 30 20 10 0
0 8 16 24 32 40 48 56 64 72 80 88 96 104 112
time (sec)
VL
VM


Subject1C-Session 5
rSO2
90 80 70 60 50 40 30 20 10 0
0 8 16 24 32 40 48 56 64 72 80 88 96 104 112 120 128 136
time (sec)
VL
VM


Subject1C-Session 6
rSO2
90 80 70 60 50 40 30 20 10 0
0 8 16 24 32 40 48 56 64 72 80 88 96 104 112 120 128
time (sec)
VL
VM

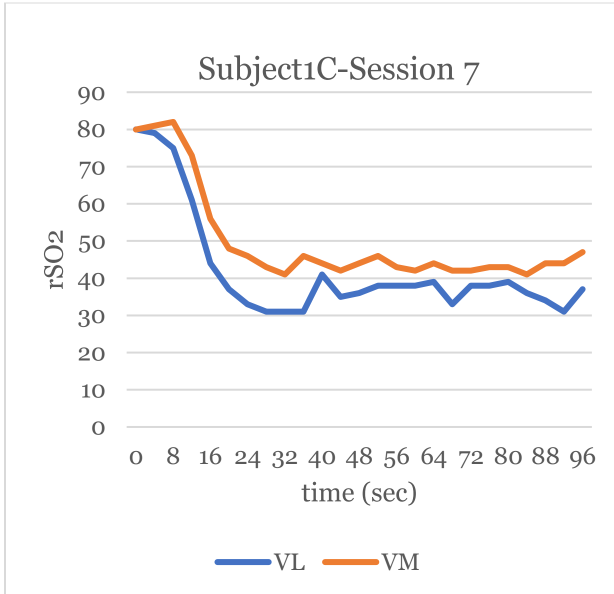
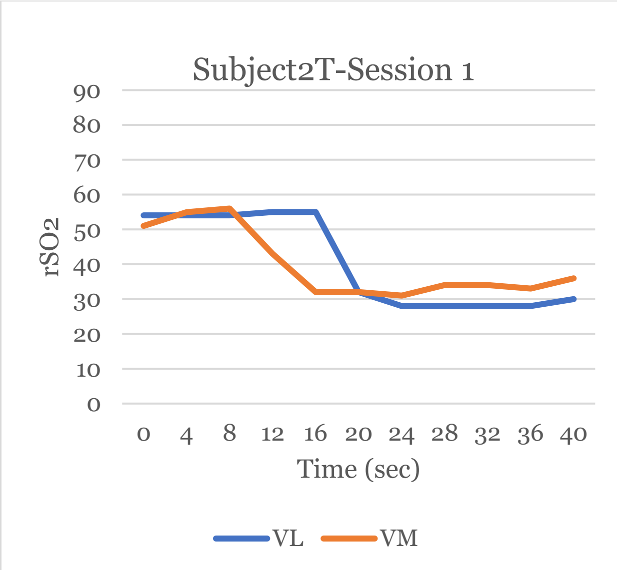
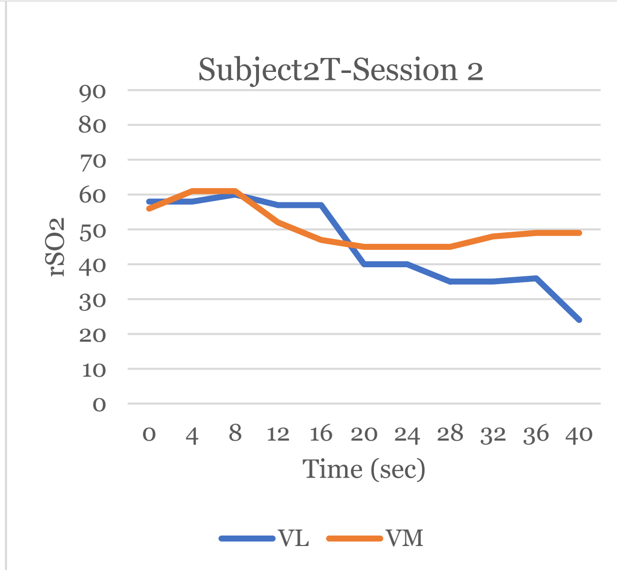
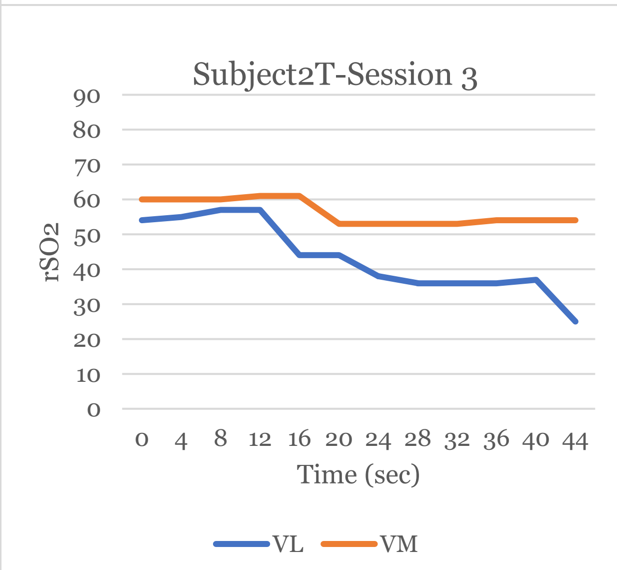
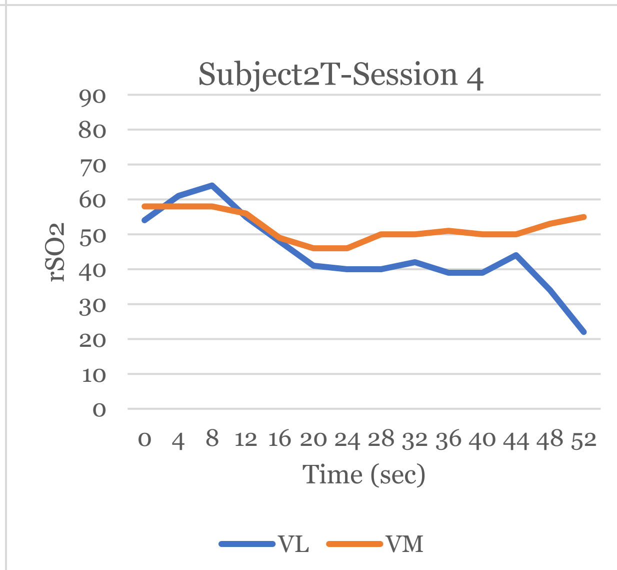


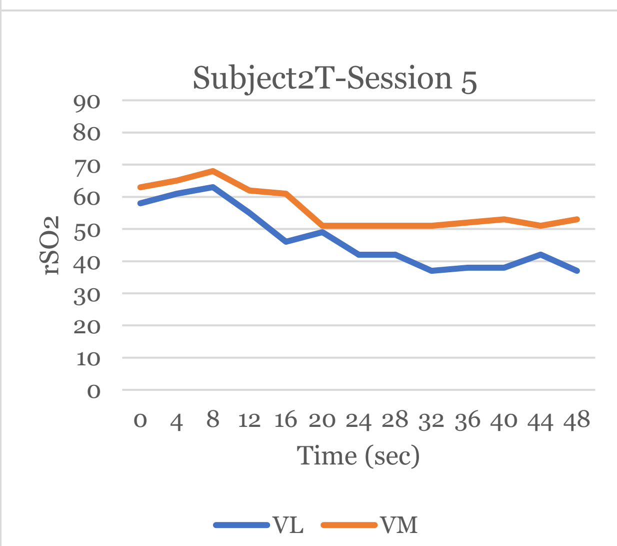
Figure I2: Regional muscle oxygenation saturation in the control knee of subject 1 across 7 sessions

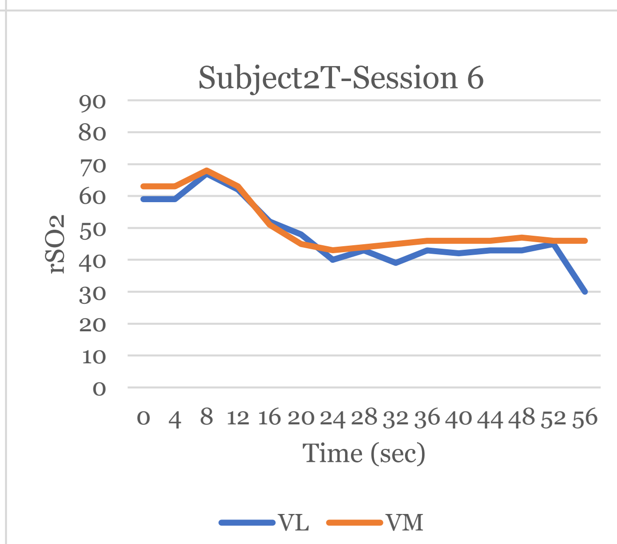

Subject2T-Session 1
rSO2
90 80 70 60 50 40 30 20 10 0
0 4 8 12 16 20 24 28 32 36 40
Time (sec)
VL VM


Subject2T-Session 2
rSO2
90 80 70 60 50 40 30 20 10 0
0 4 8 12 16 20 24 28 32 36 40
Time (sec)
VL VM


Subject2T-Session 3
rSO2
90 80 70 60 50 40 30 20 10 0
0 4 8 12 16 20 24 28 32 36 40 44
Time (sec)
VL VM


Subject2T-Session 4
rSO2
90 80 70 60 50 40 30 20 10 0
0 4 8 12 16 20 24 28 32 36 40 44 48 52
Time (sec)
VL VM


Subject2T-Session 5
rSO2
90 80 70 60 50 40 30 20 10 0
0 4 8 12 16 20 24 28 32 36 40 44 48
Time (sec)
VL VM


Subject2T-Session 6
rSO2
90 80 70 60 50 40 30 20 10 0
0 4 8 12 16 20 24 28 32 36 40 44 48 52 56
Time (sec)
VL VM

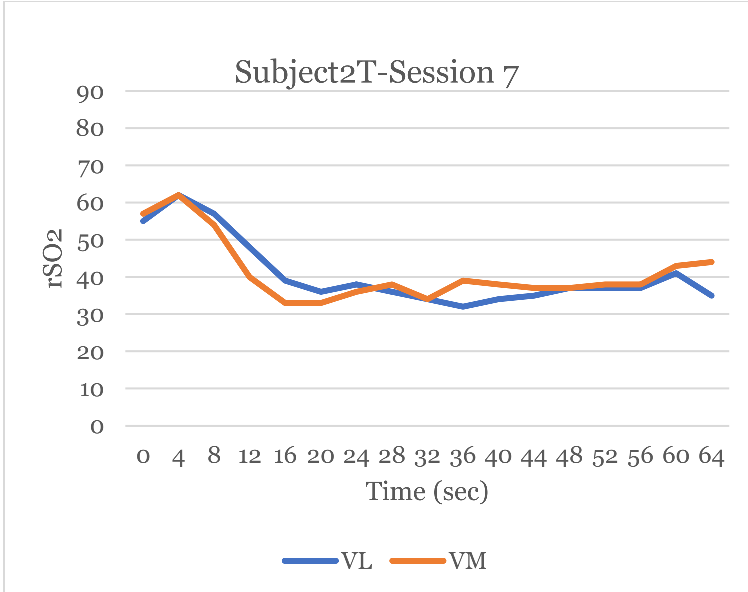
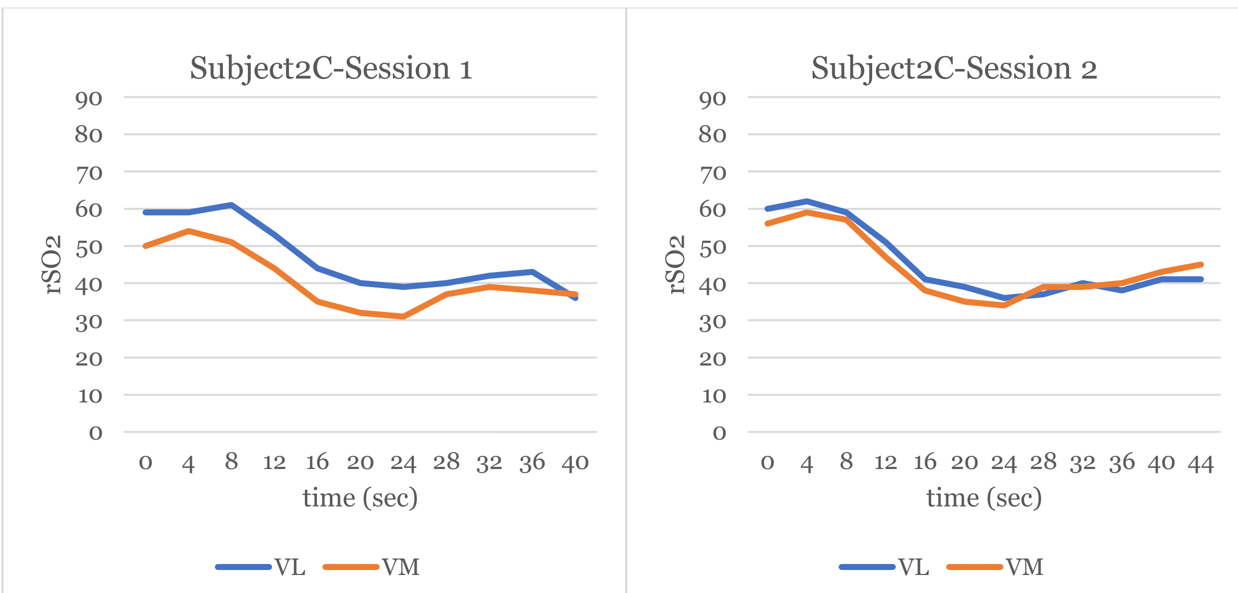


Figure I3: Regional muscle oxygenation saturation in the treatment knee of subject 2 across 7 sessions



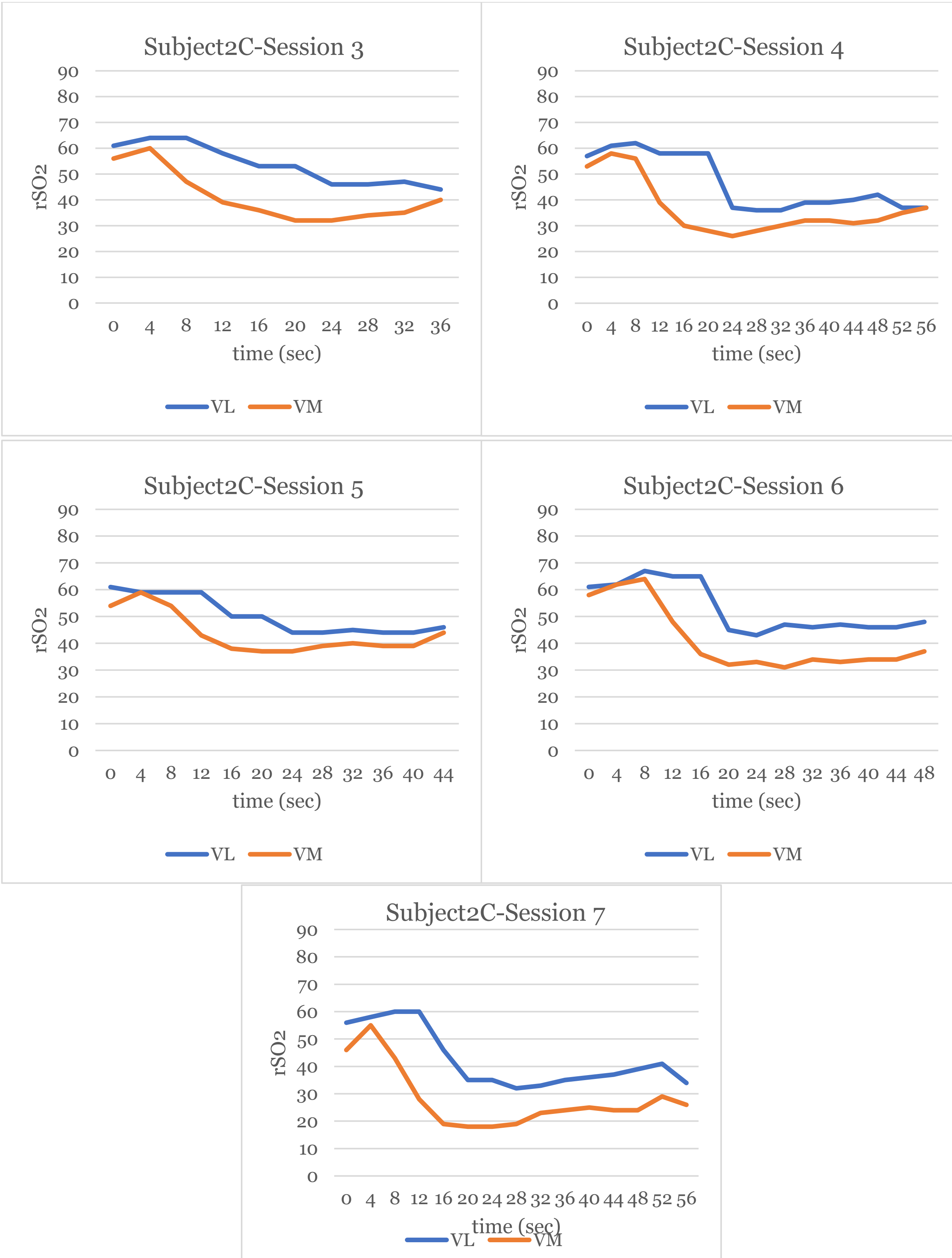
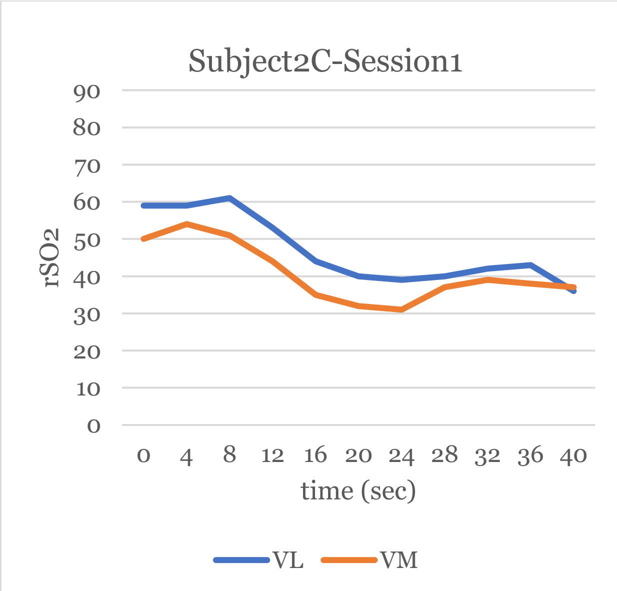
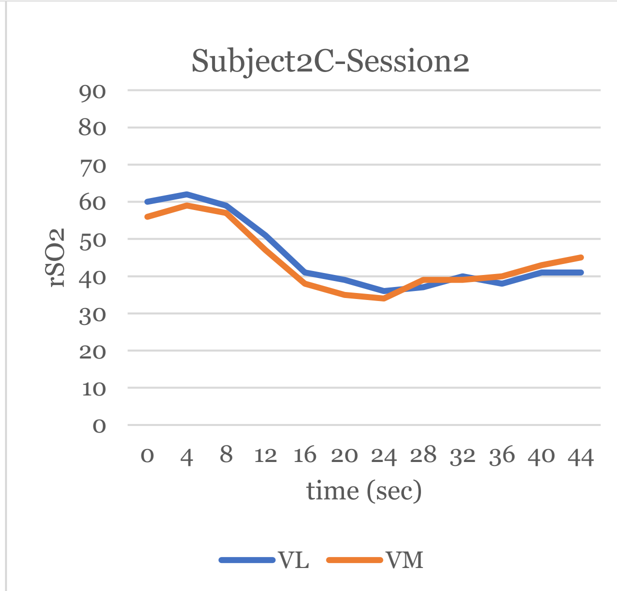
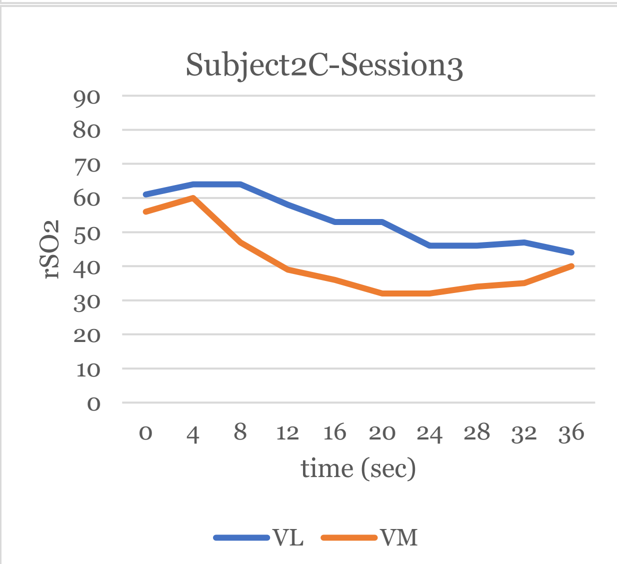
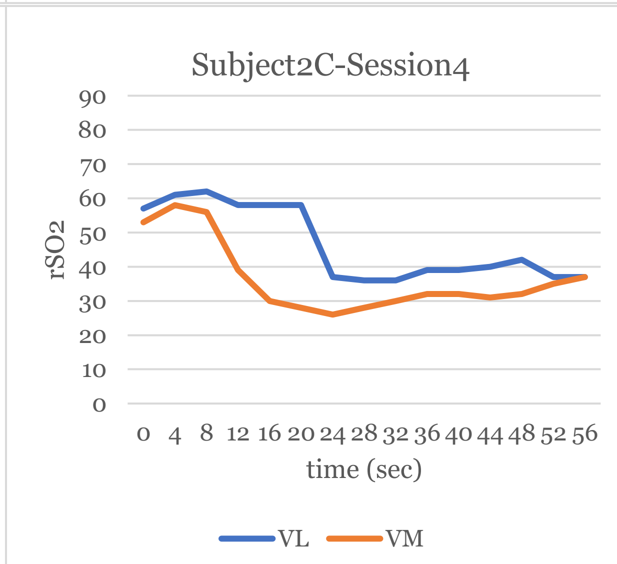


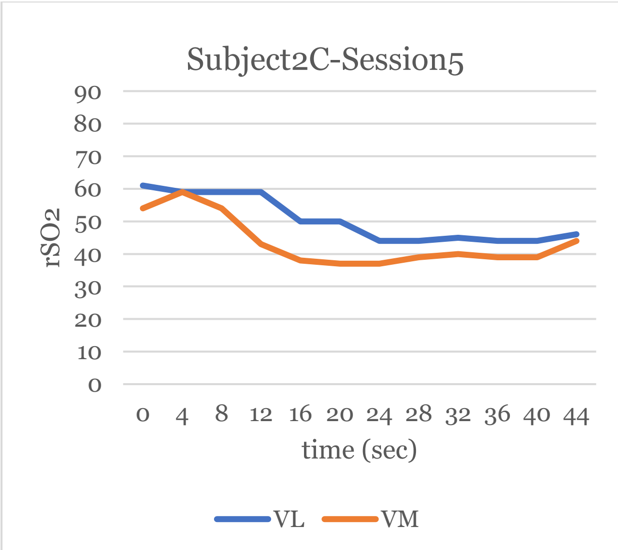
Figure I4: Regional muscle oxygenation saturation in the control knee of subject 2 across 7 sessions

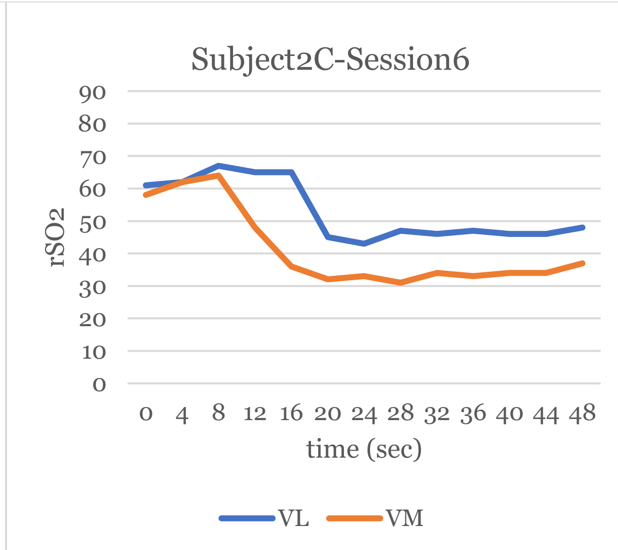

Subject2C-Session1
rSO2
90
80
70
60
50
40
30
20
10
0
0 4 8 12 16 20 24 28 32 36 40
time (sec)
VL
VM


Subject2C-Session2
rSO2
90
80
70
60
50
40
30
20
10
0
0 4 8 12 16 20 24 28 32 36 40 44
time (sec)
VL
VM


Subject2C-Session3
rSO2
90
80
70
60
50
40
30
20
10
0
0 4 8 12 16 20 24 28 32 36
time (sec)
VL
VM


Subject2C-Session4
rSO2
90
80
70
60
50
40
30
20
10
0
0 4 8 12 16 20 24 28 32 36 40 44 48 52 56
time (sec)
VL
VM





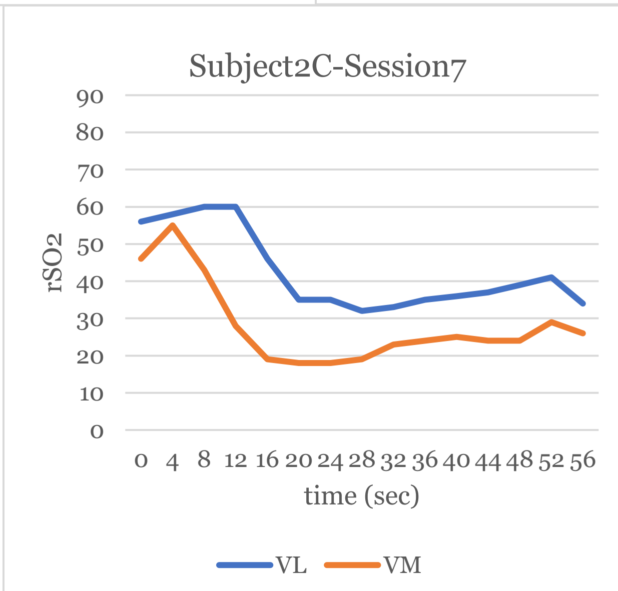
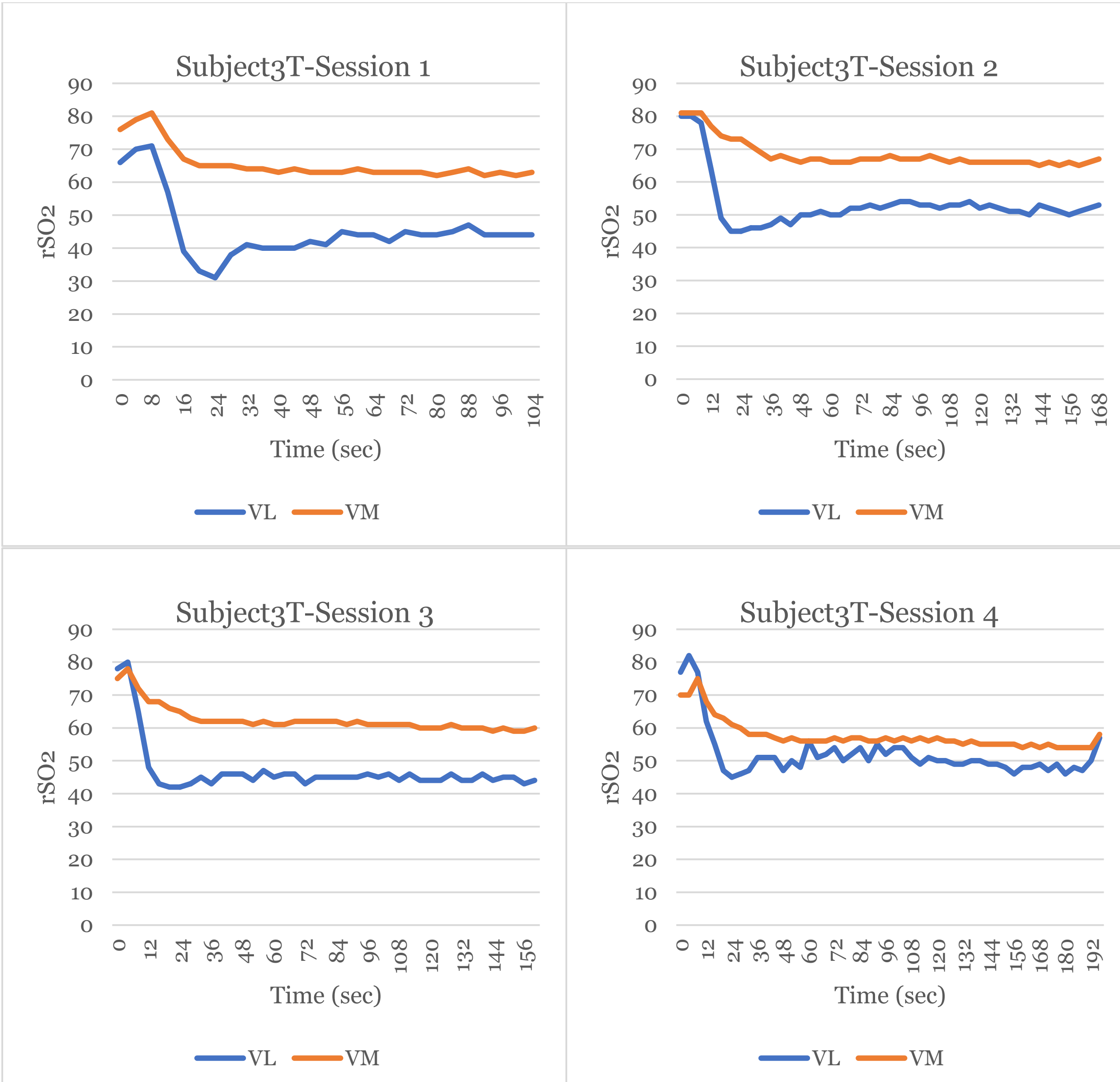


Figure I4: Regional muscle oxygenation saturation in the control knee of subject 2 across 7 sessions


Subject3T-Session 1
rSO2
Time (sec)
VL
VM
Subject3T-Session 2
rSO2
Time (sec)
VL
VM
Subject3T-Session 3
rSO2
Time (sec)
VL
VM
Subject3T-Session 4
rSO2
Time (sec)
VL
VM

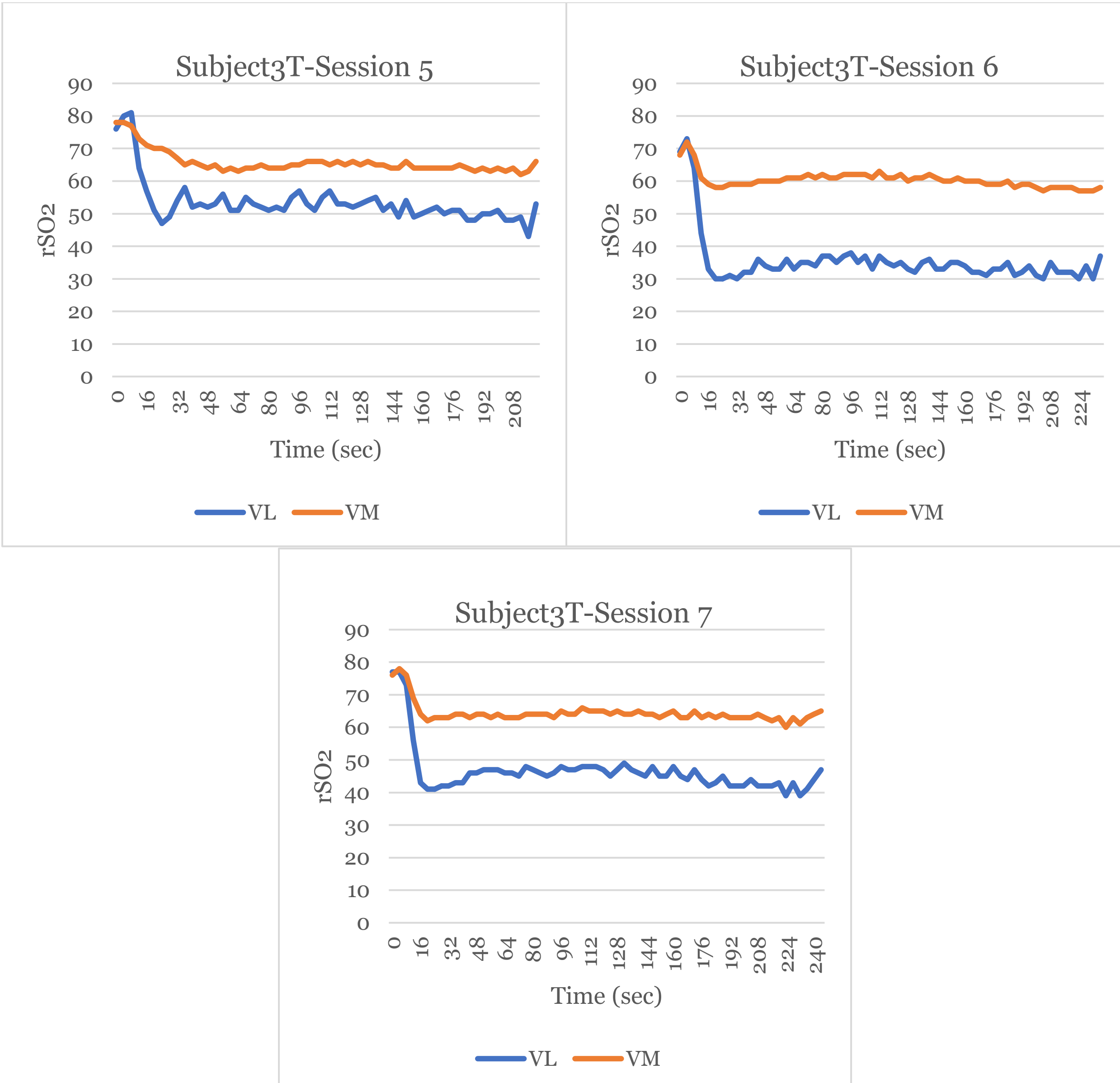
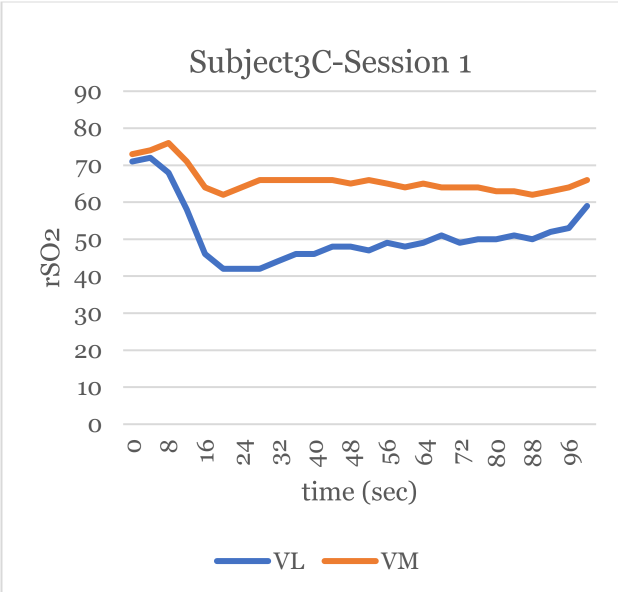
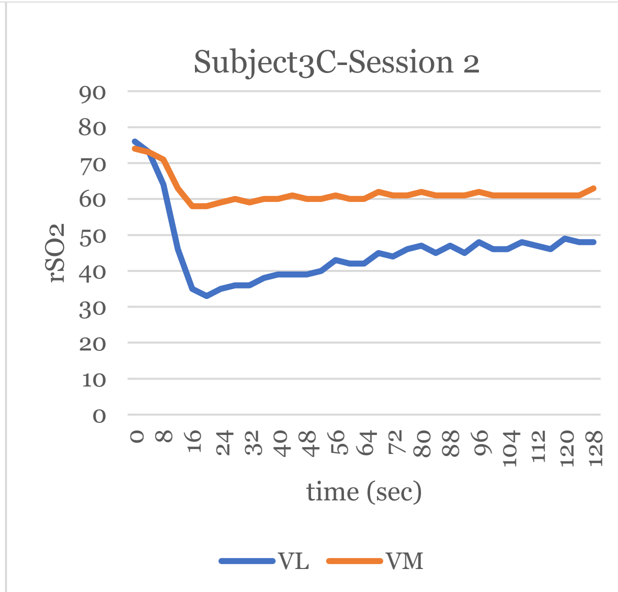
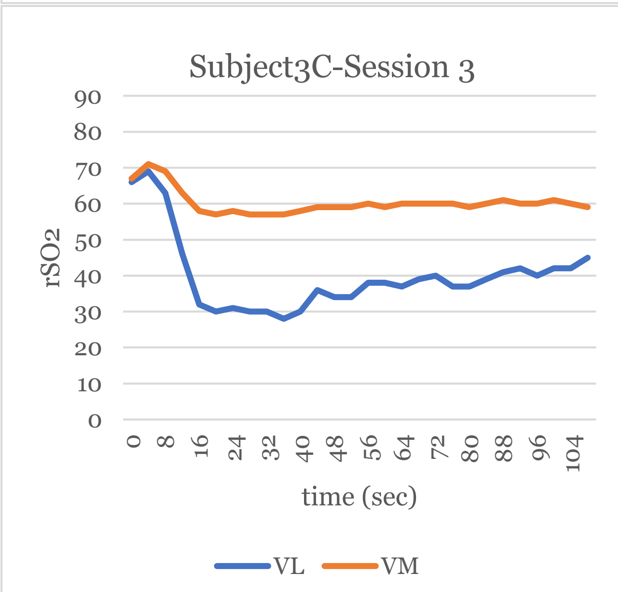
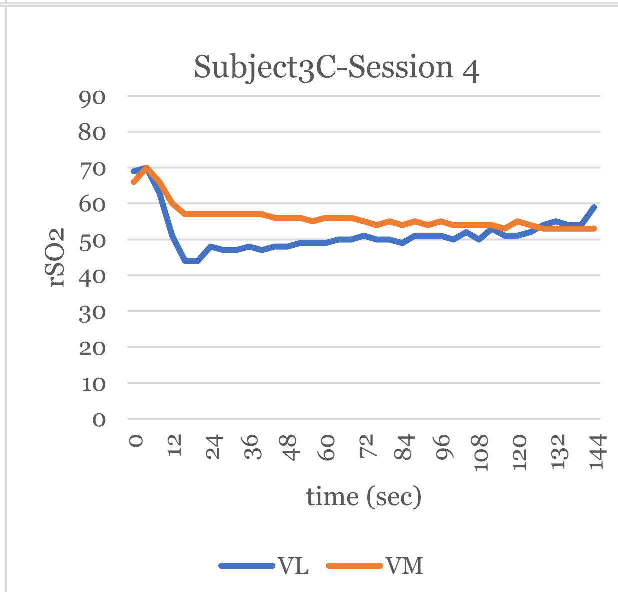


Figure I5: Regional muscle oxygenation saturation in the treatment knee of subject 3 across 7 sessions


Subject3C-Session 1
rSO2
time (sec)
VL
VM

Subject3C-Session 2
rSO2
time (sec)
VL
VM

Subject3C-Session 3
rSO2
time (sec)
VL
VM

Subject3C-Session 4
rSO2
time (sec)
VL
VM

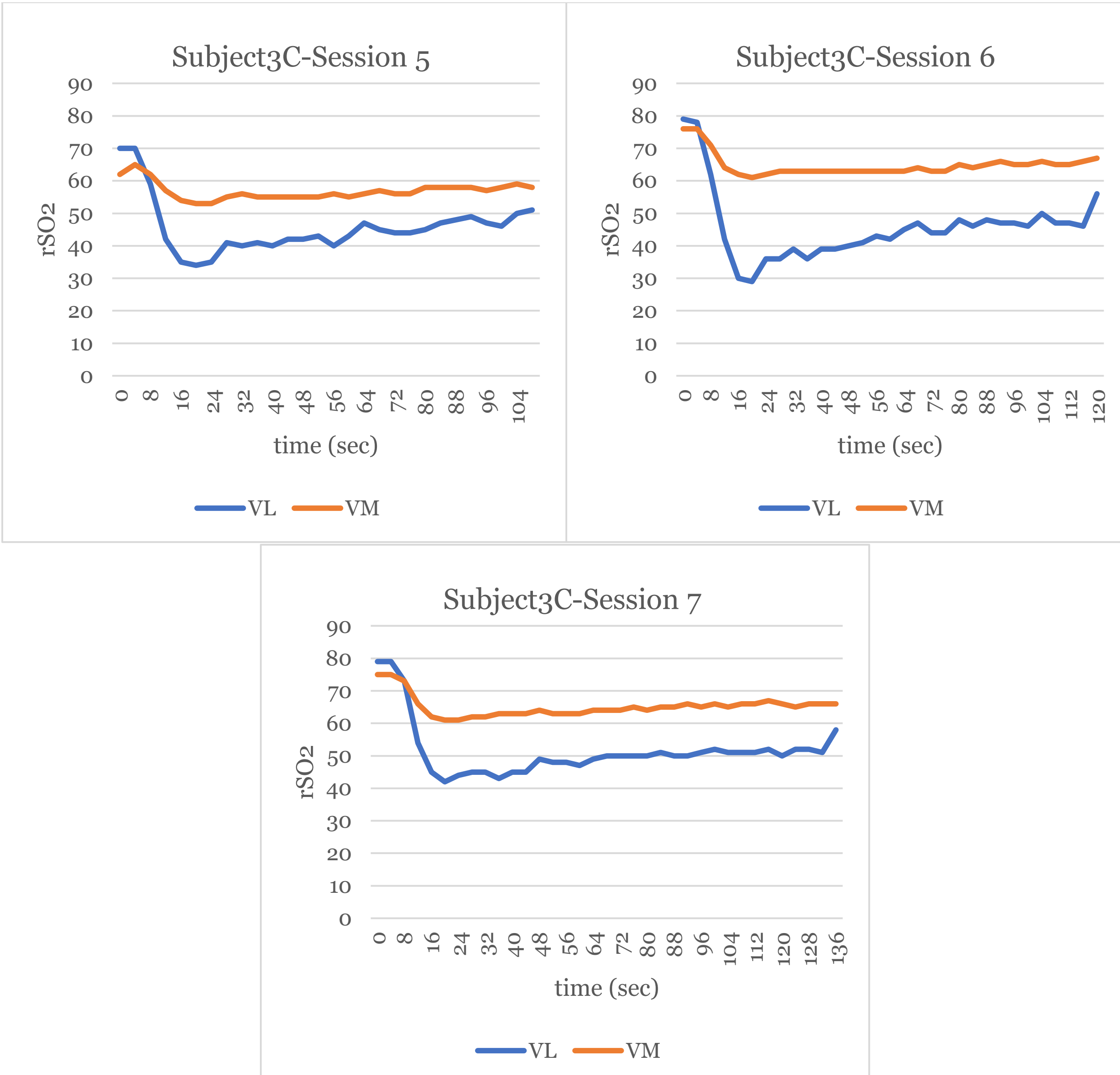
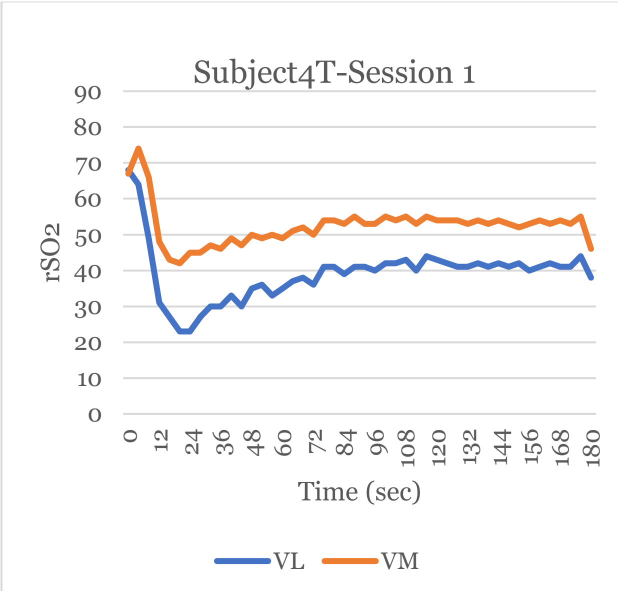
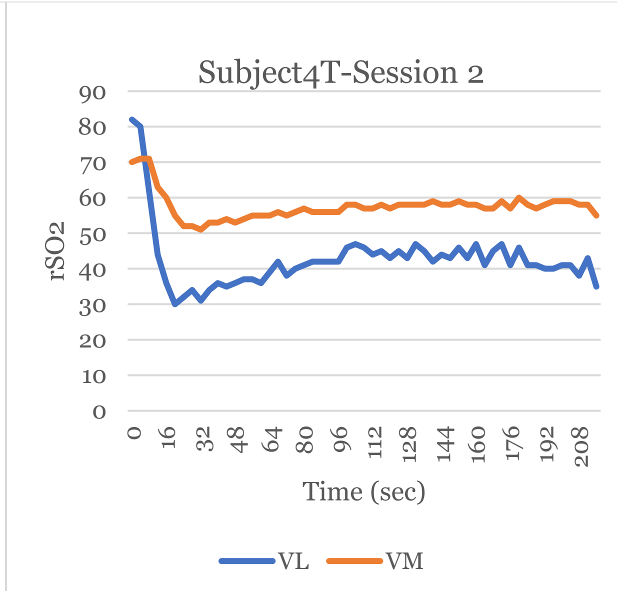
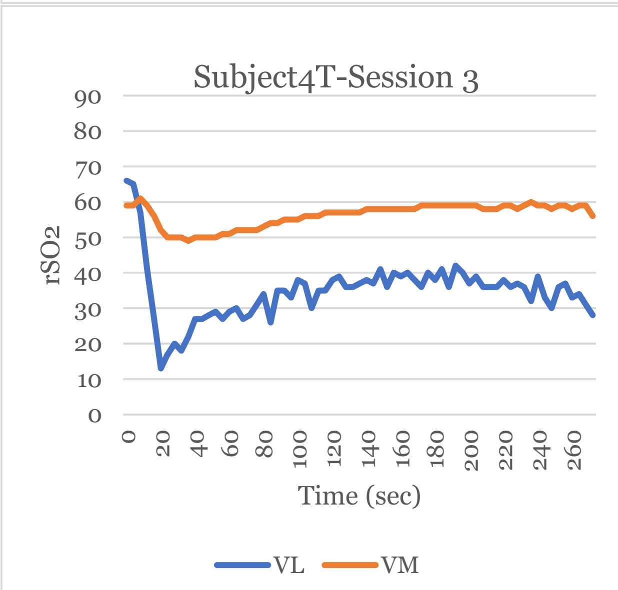
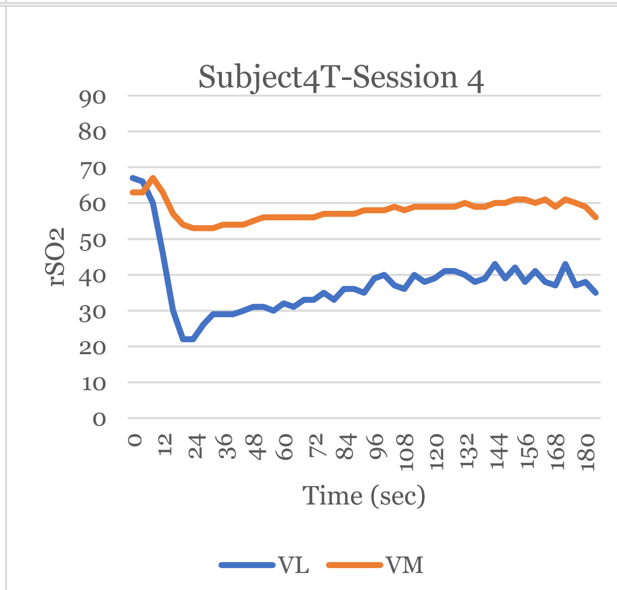


Figure I6: Regional muscle oxygenation saturation in the control knee of subject 3 across 7 sessions


Subject4T-Session 1
rSO2
90
80
70
60
50
40
30
20
10
0
0
12
24
36
48
60
72
84
96
108
120
132
144
156
168
180
Time (sec)
VL
VM


Subject4T-Session 2
rSO2
90
80
70
60
50
40
30
20
10
0
0
16
32
48
64
80
96
112
128
144
160
176
192
208
Time (sec)
VL
VM


Subject4T-Session 3
rSO2
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
140
160
180
200
220
240
260
Time (sec)
VL
VM


Subject4T-Session 4
rSO2
90
80
70
60
50
40
30
20
10
0
0
12
24
36
48
60
72
84
96
108
120
132
144
156
168
180
Time (sec)
VL
VM

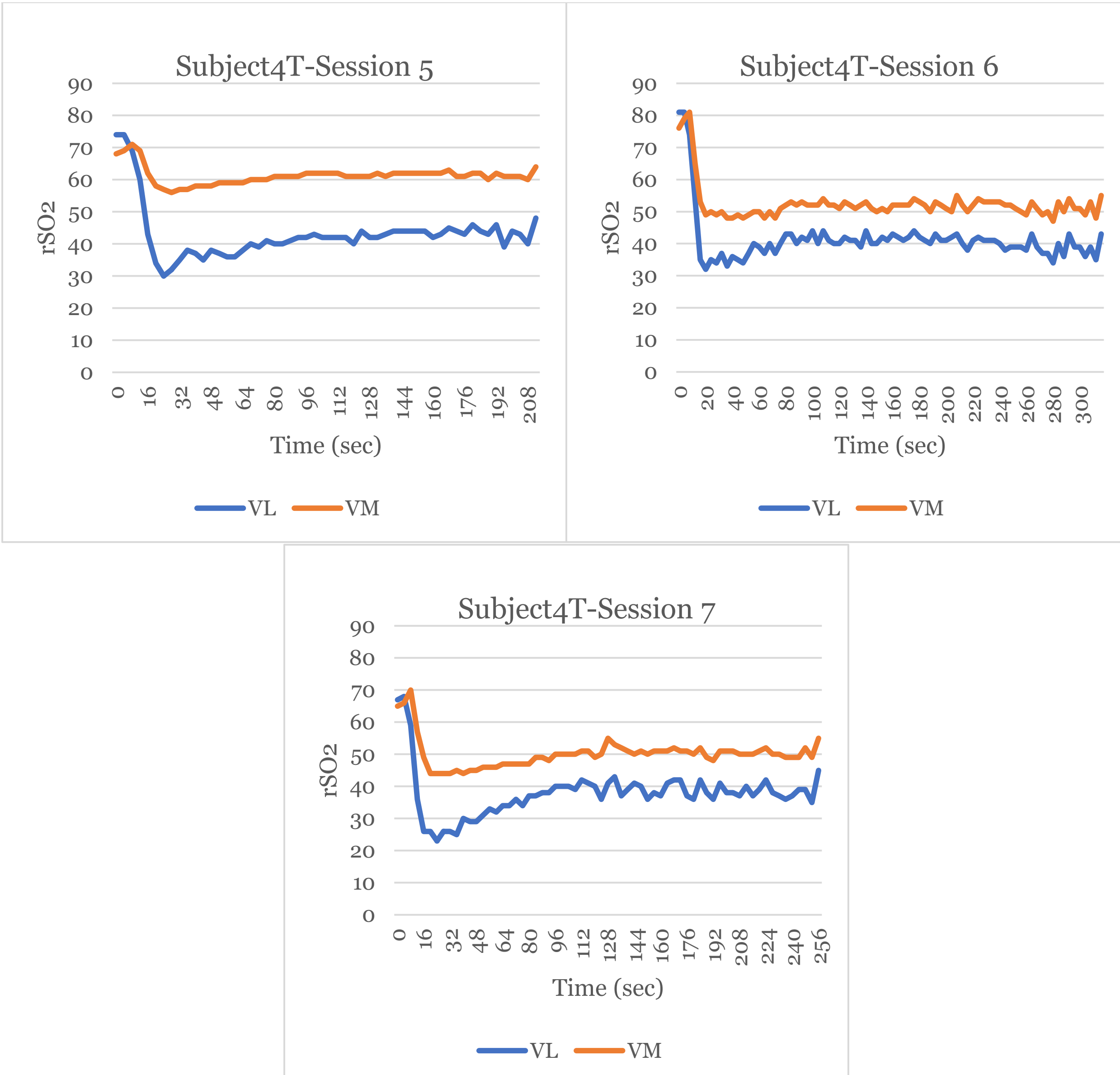


Figure I7: Regional muscle oxygenation saturation in the treatment knee of subject 4 across 7 sessions

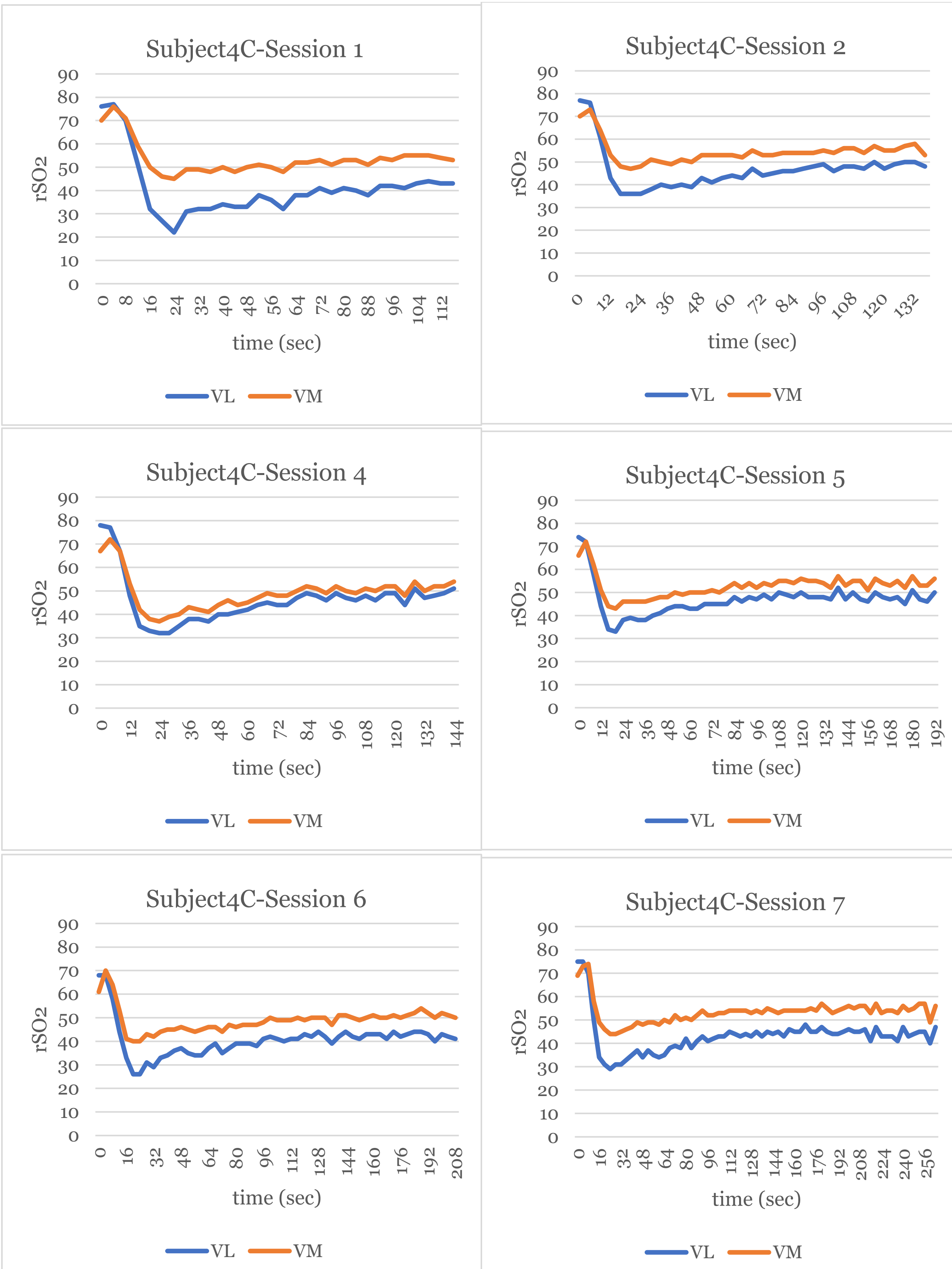
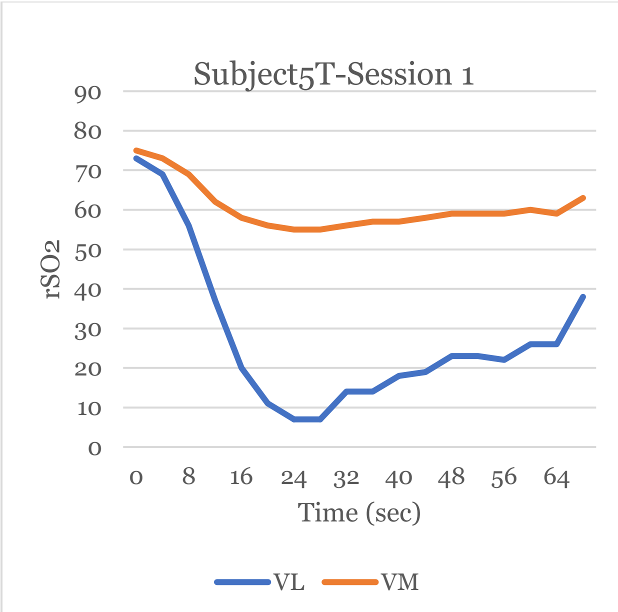
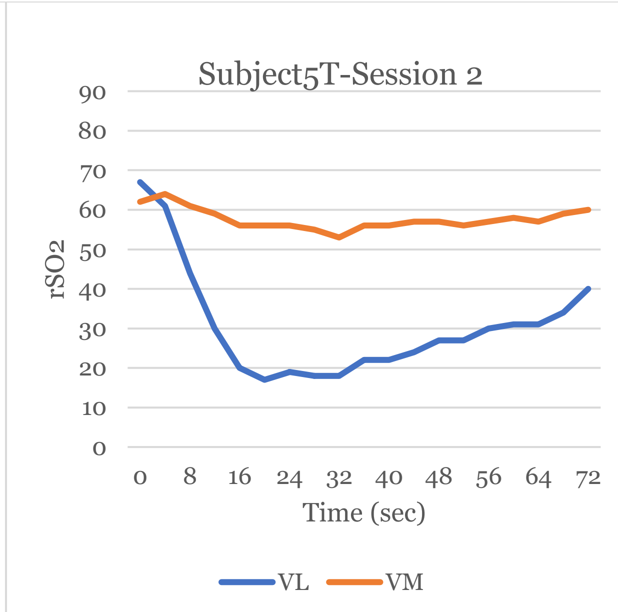
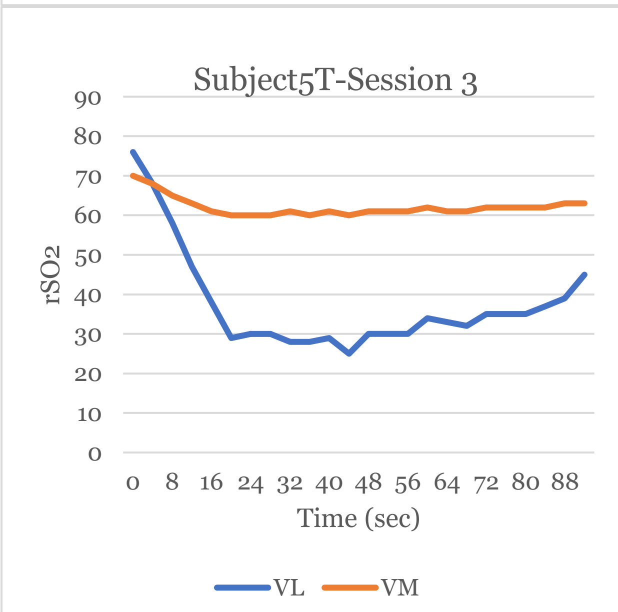
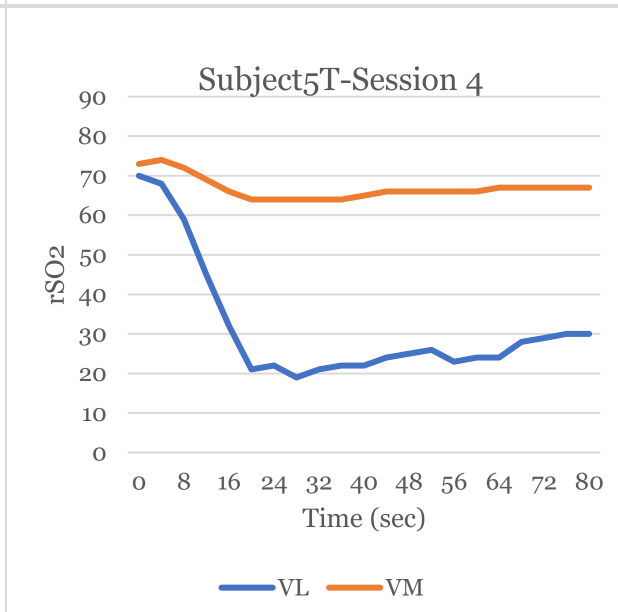


Figure I8: Regional muscle oxygenation saturation in the control knee of subject 4 across 7 sessions


Subject5T-Session 1
rSO2
90
80
70
60
50
40
30
20
10
0
0
8
16
24
32
40
48
56
64
Time (sec)
VL
VM


Subject5T-Session 2
rSO2
90
80
70
60
50
40
30
20
10
0
0
8
16
24
32
40
48
56
64
72
Time (sec)
VL
VM


Subject5T-Session 3
rSO2
90
80
70
60
50
40
30
20
10
0
0
8
16
24
32
40
48
56
64
72
80
88
Time (sec)
VL
VM


Subject5T-Session 4
rSO2
90
80
70
60
50
40
30
20
10
0
0
8
16
24
32
40
48
56
64
72
80
Time (sec)
VL
VM

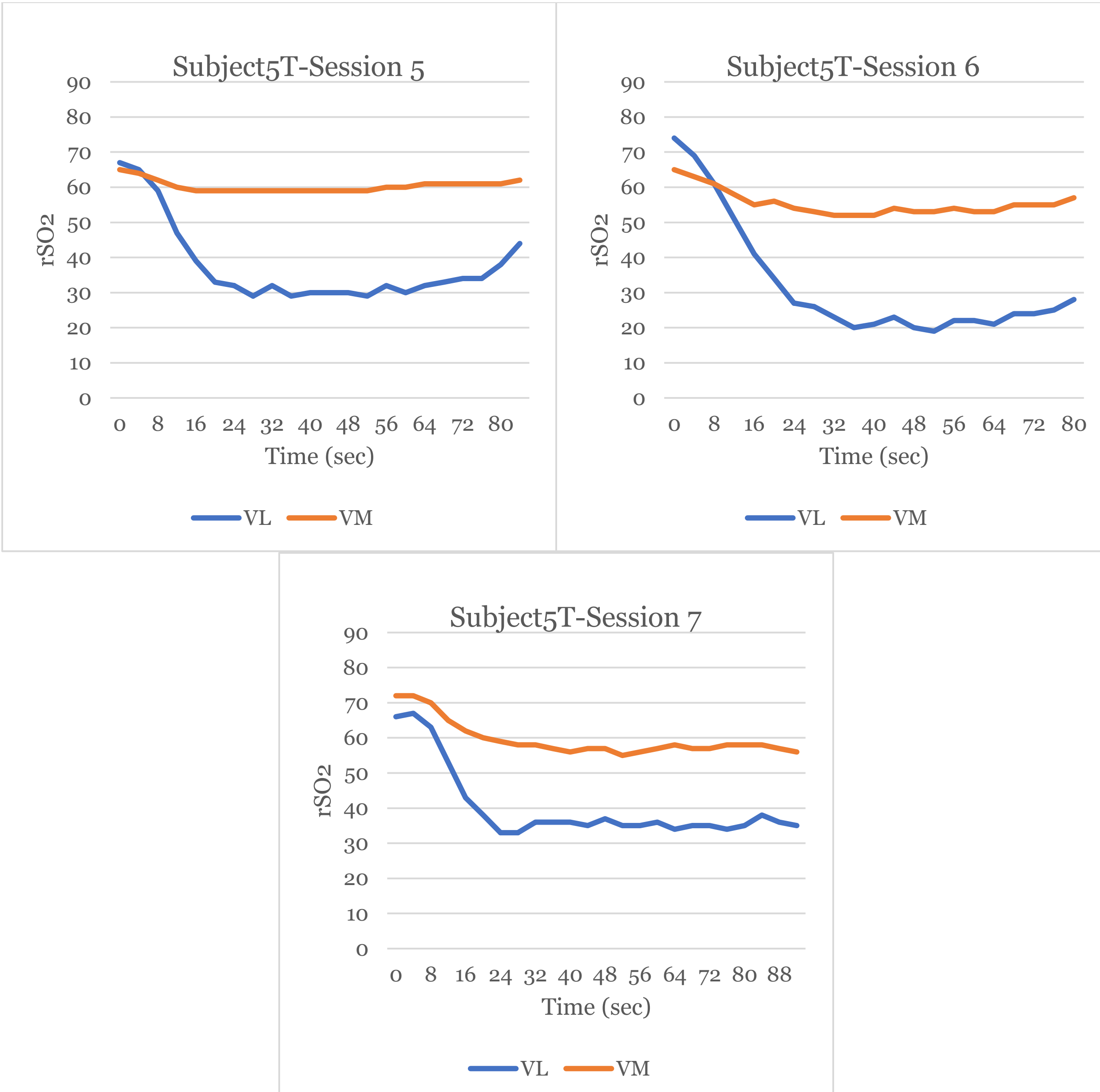
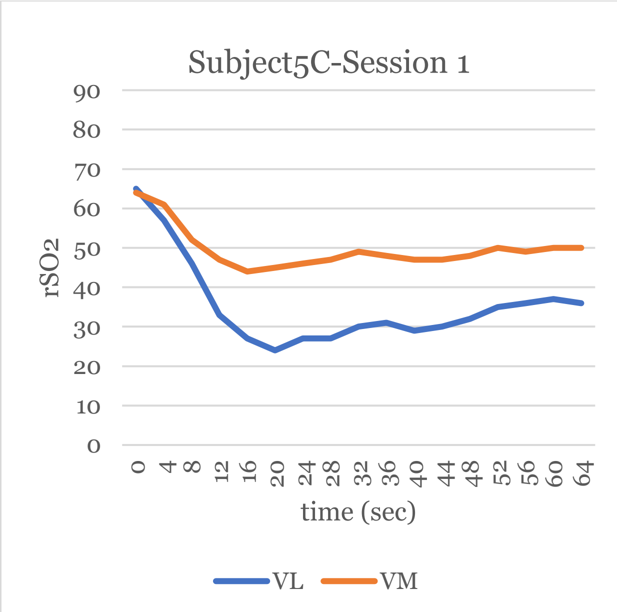
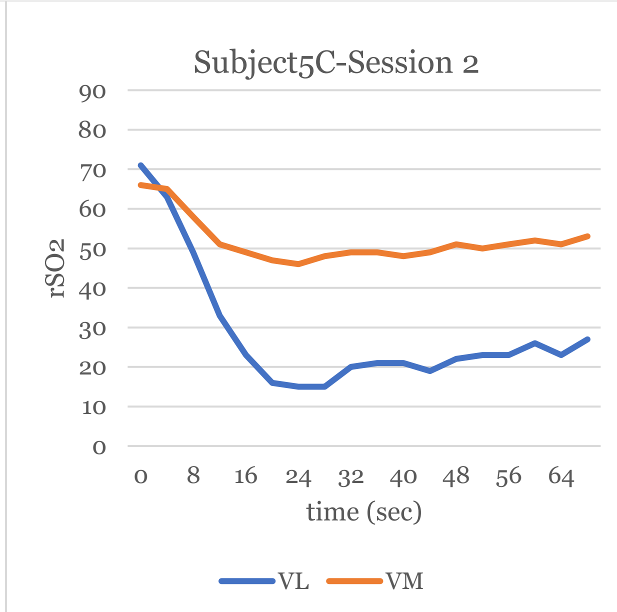
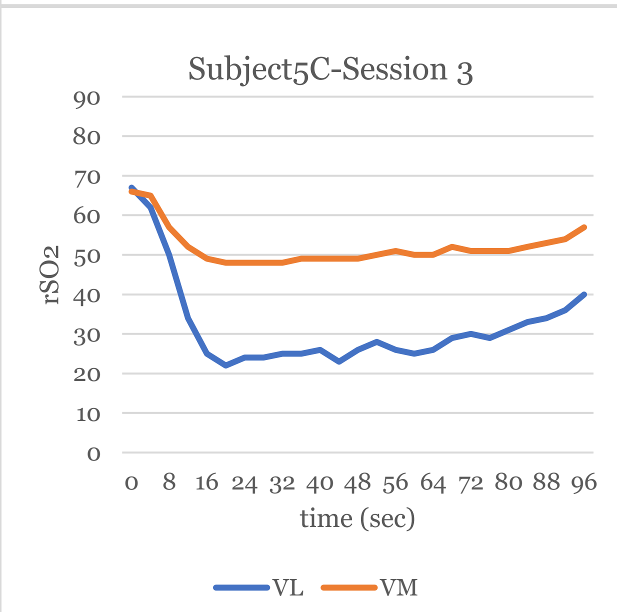
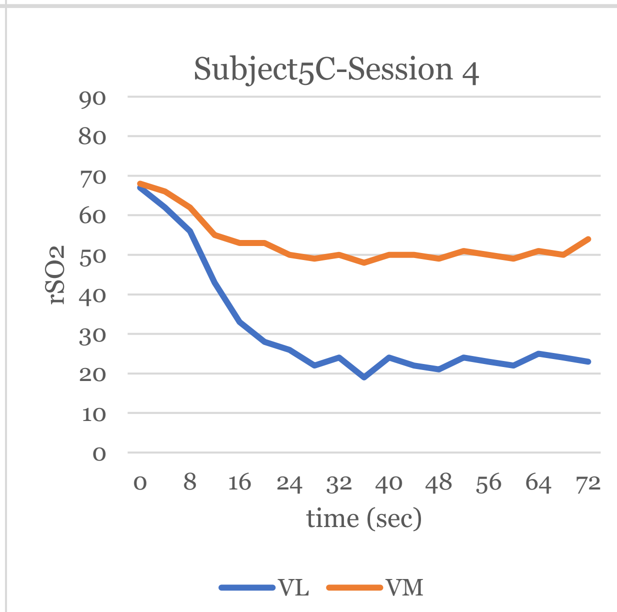


Figure I9: Regional muscle oxygenation saturation in the treatment knee of subject 5 across 7 sessions


Subject5C-Session 1
90
80
70
60
50
40
30
20
10
0
rSO2
0 4 8 12 16 20 24 28 32 36 40 44 48 52 56 60 64
time (sec)
VL
VM


Subject5C-Session 2
90
80
70
60
50
40
30
20
10
0
rSO2
0 8 16 24 32 40 48 56 64
time (sec)
VL
VM


Subject5C-Session 3
90
80
70
60
50
40
30
20
10
0
rSO2
0 8 16 24 32 40 48 56 64 72 80 88 96
time (sec)
VL
VM


Subject5C-Session 4
90
80
70
60
50
40
30
20
10
0
rSO2
0 8 16 24 32 40 48 56 64 72
time (sec)
VL
VM

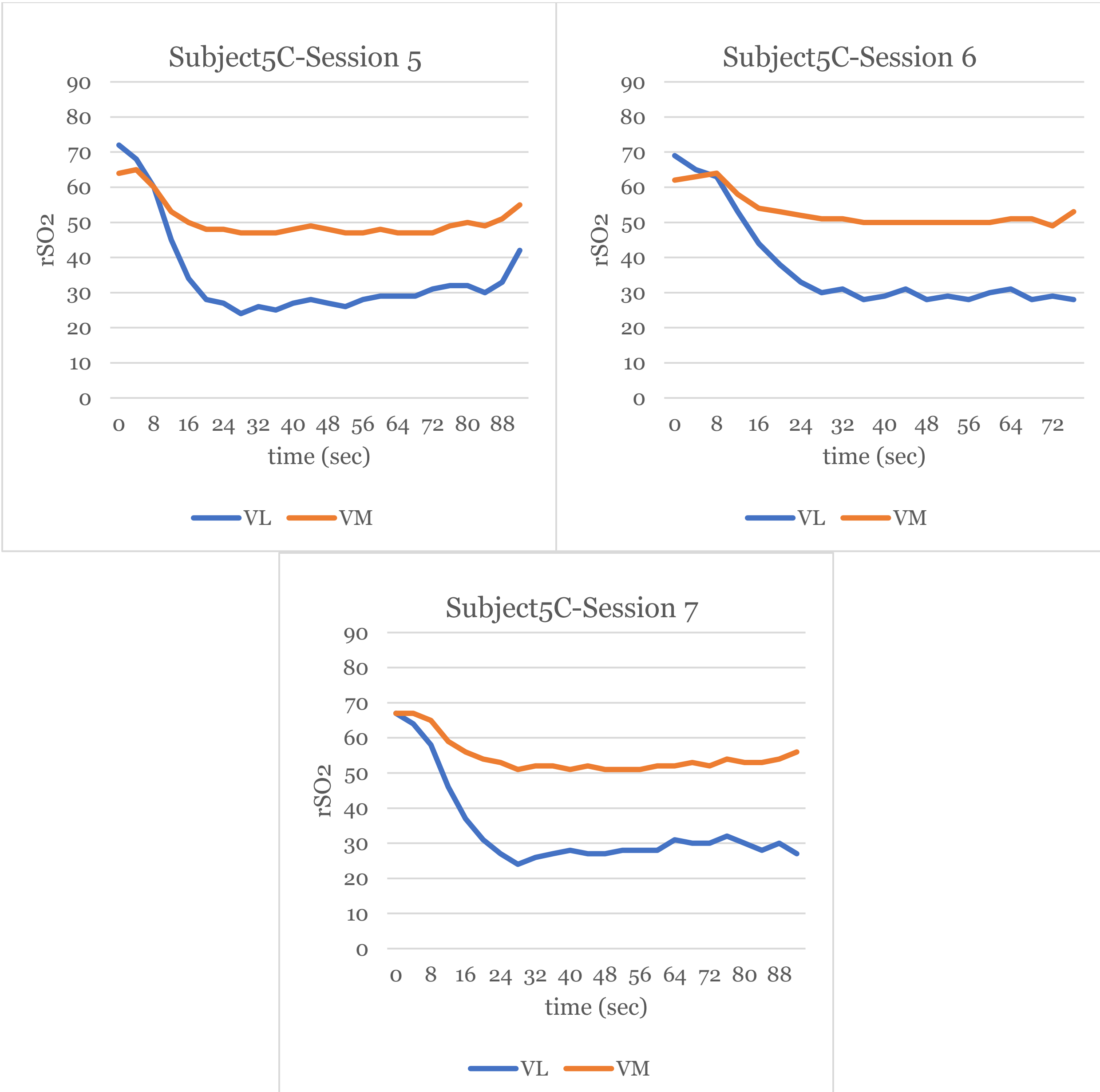


Figure I10: Regional muscle oxygenation saturation in the control knee of subject 5 across 7 sessions

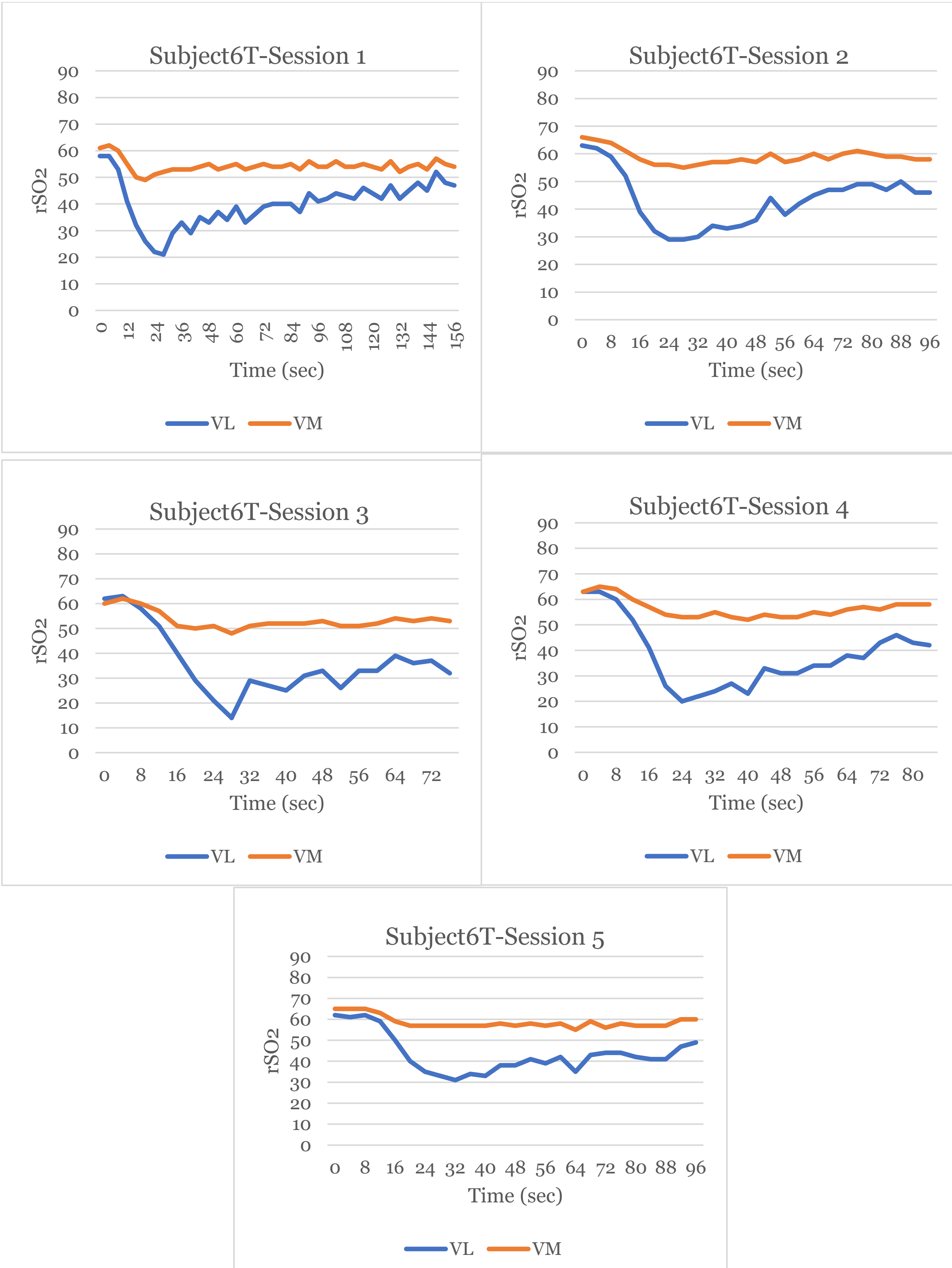


Figure I11: Regional muscle oxygenation saturation in the treatment knee of subject 6 across 7 sessions

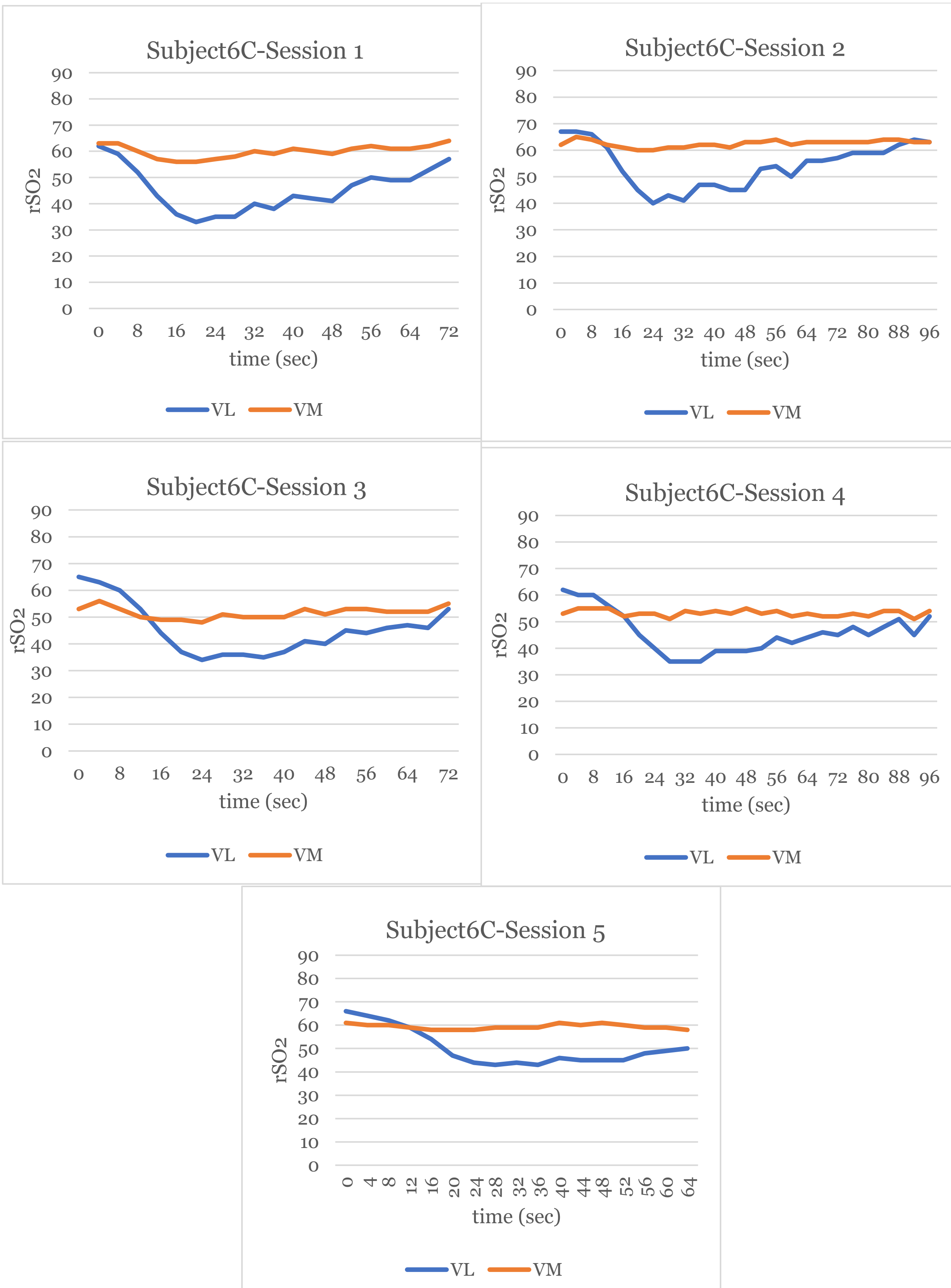
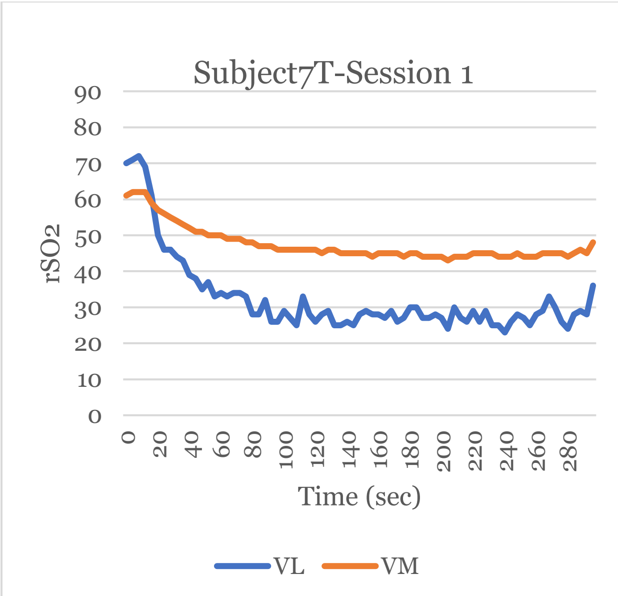
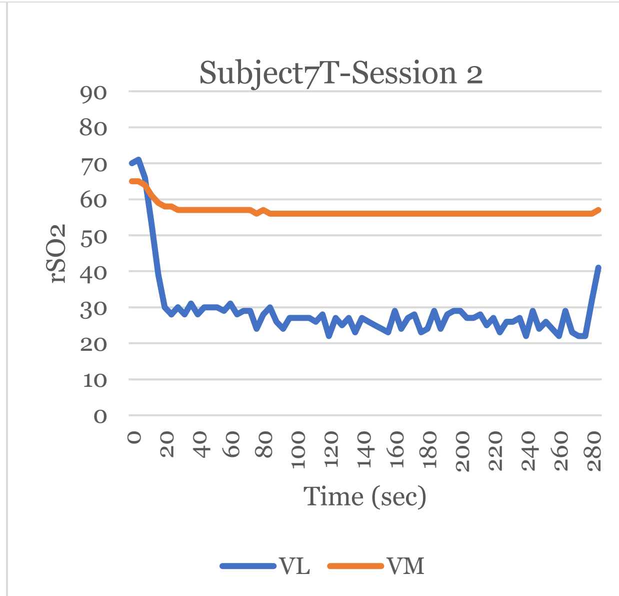
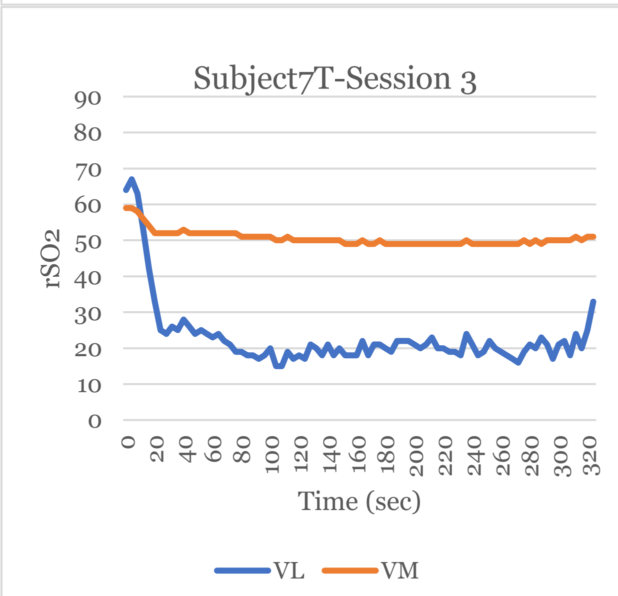
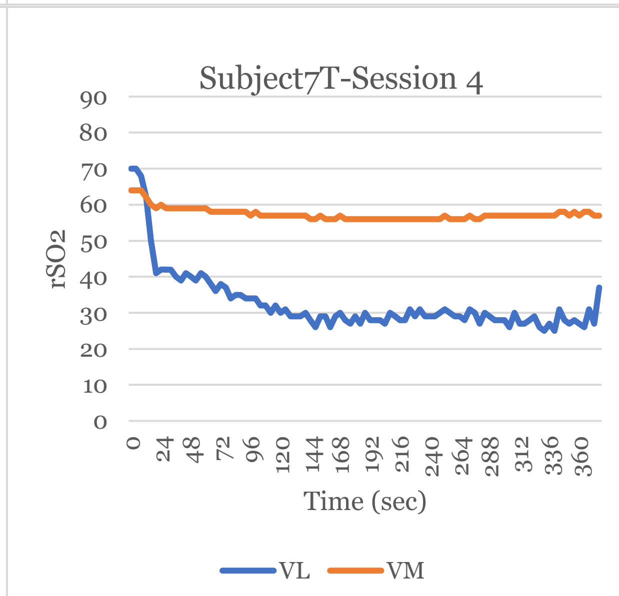


Figure I12: Regional muscle oxygenation saturation in the control knee of subject 6 across 7 sessions


Subject7T-Session 1
rSO2
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
Time (sec)
VL
VM


Subject7T-Session 2
rSO2
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
Time (sec)
VL
VM


Subject7T-Session 3
rSO2
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
Time (sec)
VL
VM


Subject7T-Session 4
rSO2
90
80
70
60
50
40
30
20
10
0
0
24
48
72
96
120
144
168
192
216
240
264
288
312
336
360
Time (sec)
VL
VM

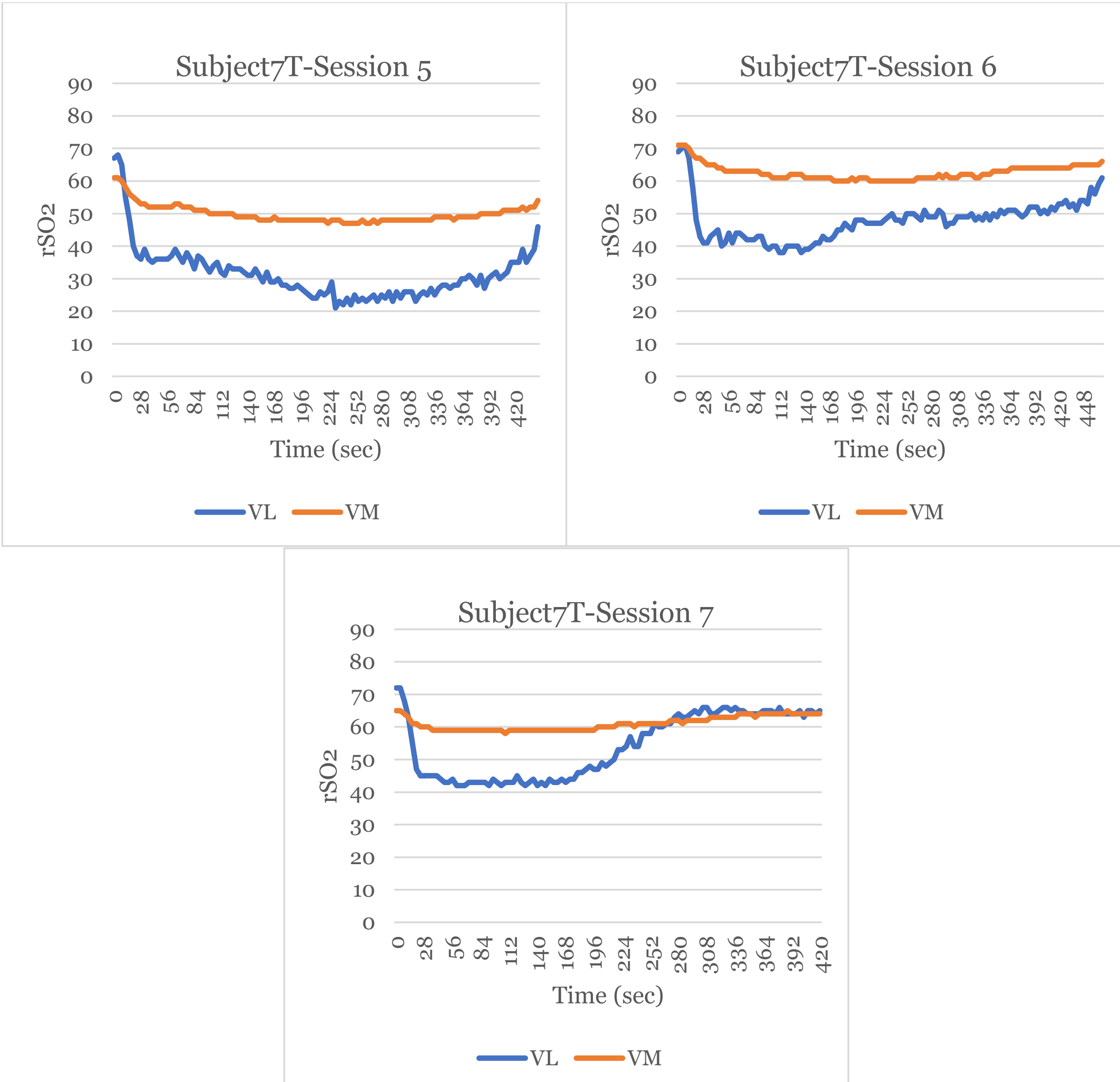
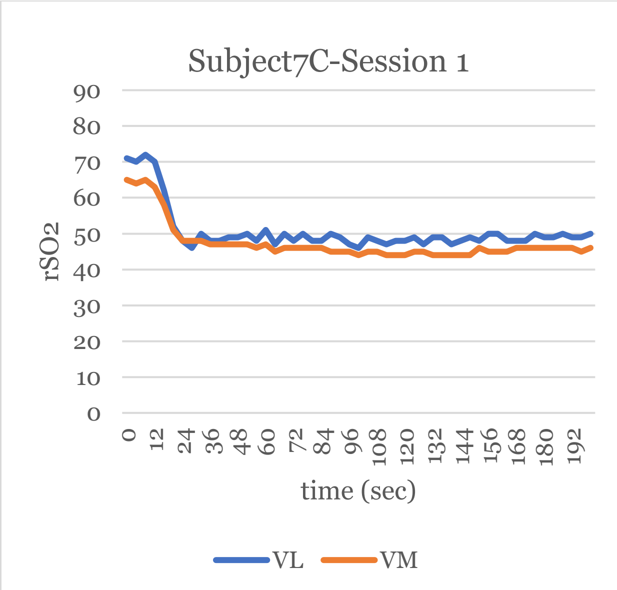
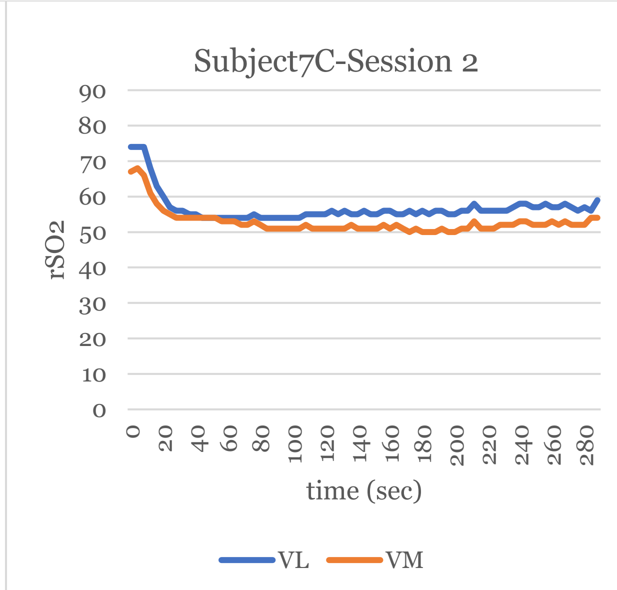
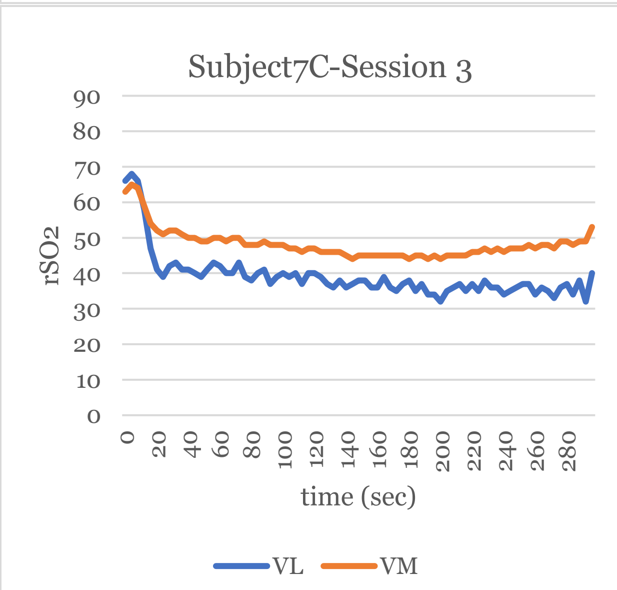
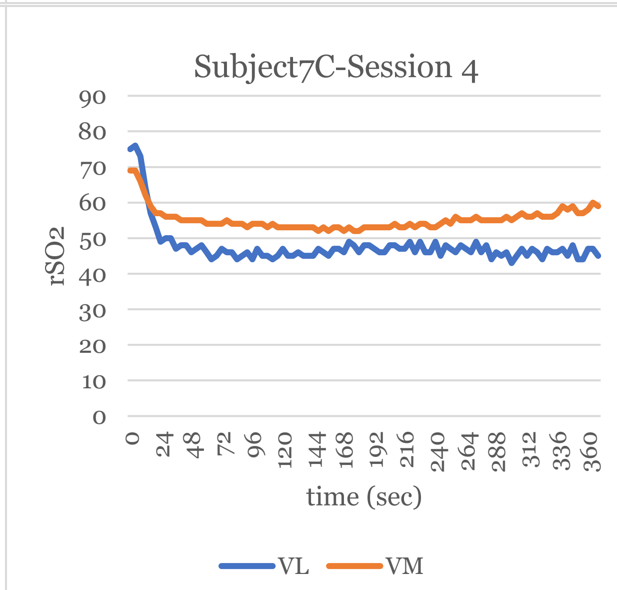


Figure I13: Regional muscle oxygenation saturation in the treatment knee of subject 7 across 7 sessions


Subject7C-Session 1
rSO2
90
80
70
60
50
40
30
20
10
0
0
12
24
36
48
60
72
84
96
108
120
132
144
156
168
180
192
time (sec)
VL
VM


Subject7C-Session 2
rSO2
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
time (sec)
VL
VM


Subject7C-Session 3
rSO2
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
time (sec)
VL
VM


Subject7C-Session 4
rSO2
90
80
70
60
50
40
30
20
10
0
0
24
48
72
96
120
144
168
192
216
240
264
288
312
336
360
time (sec)
VL
VM

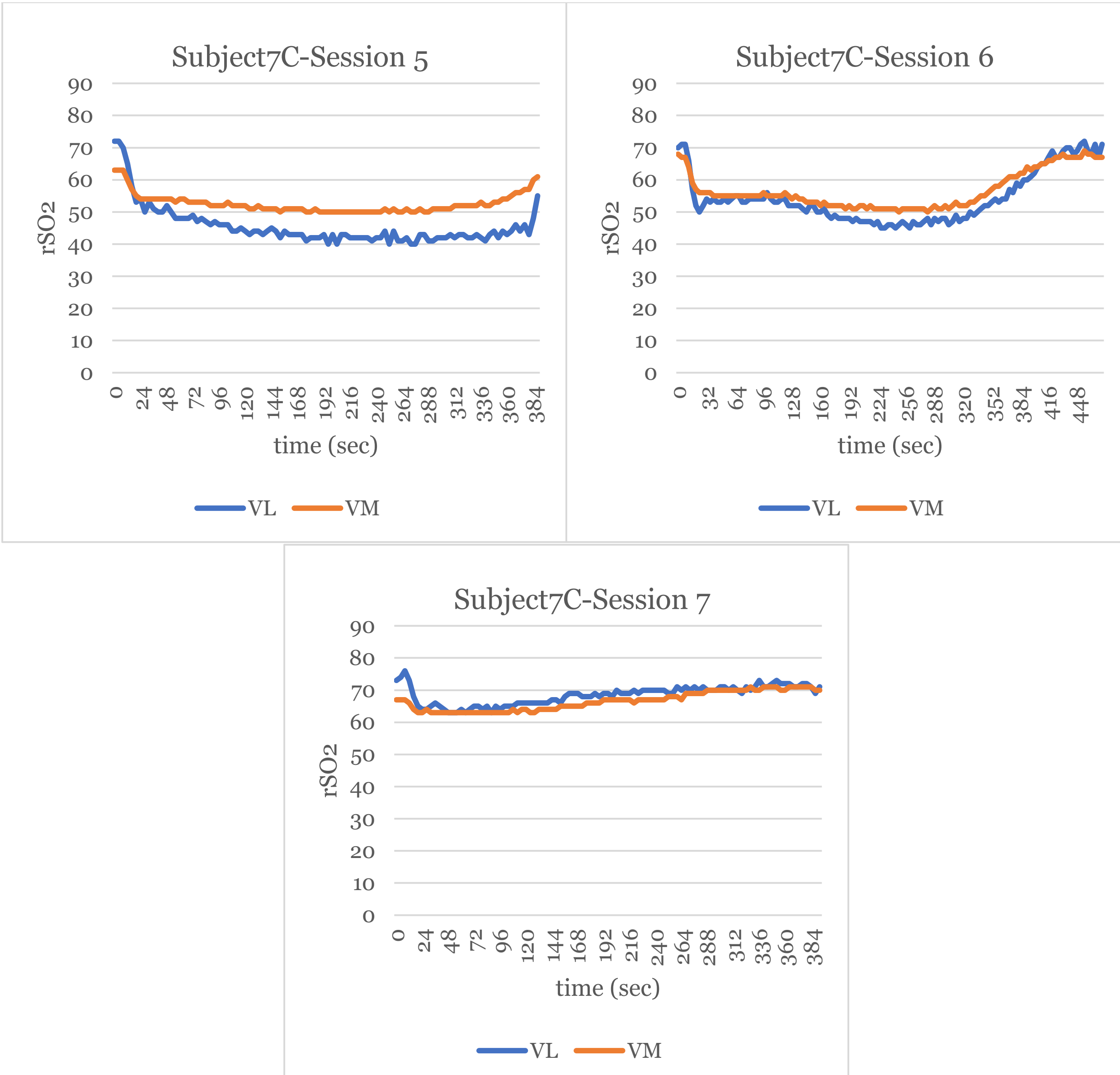
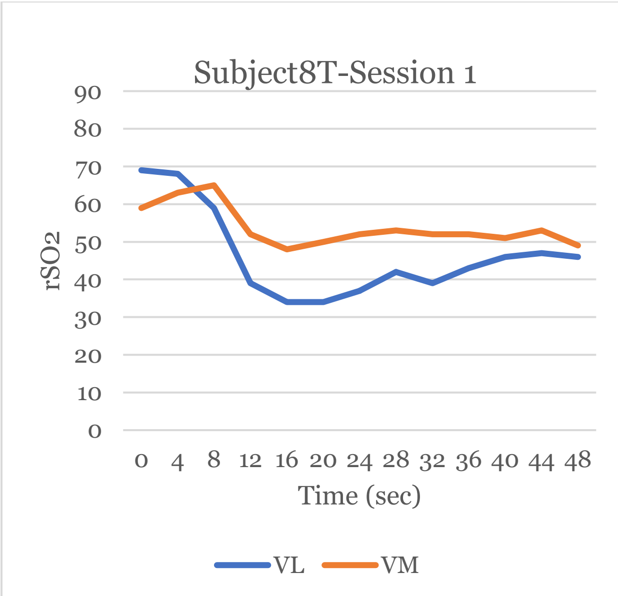
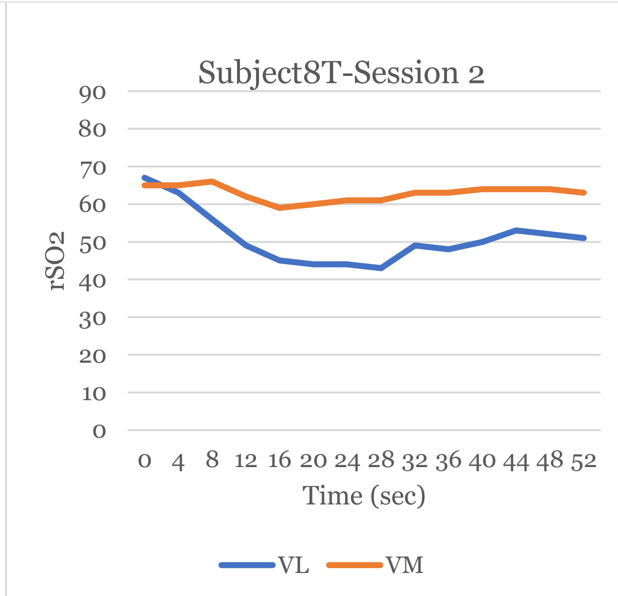
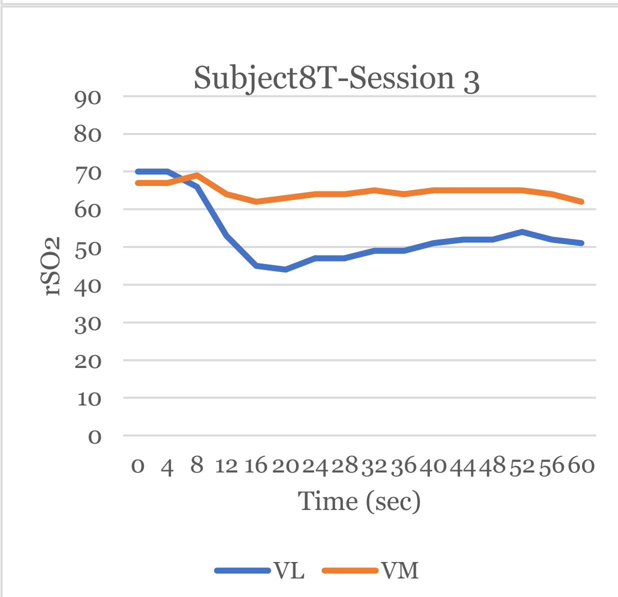
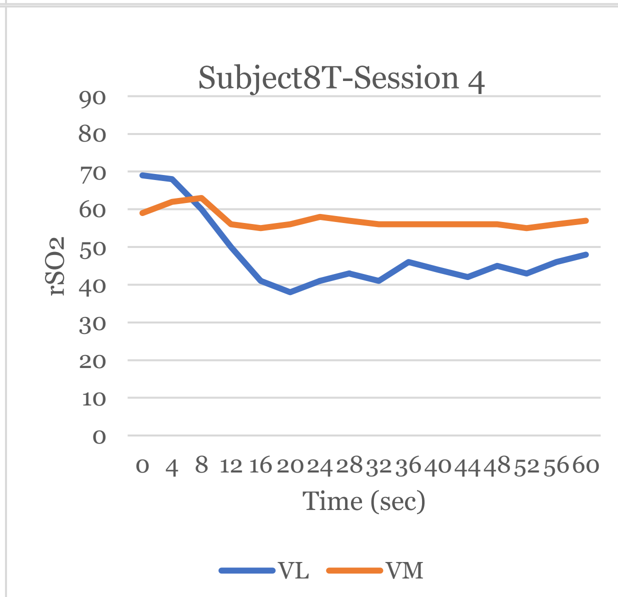


Figure I14: Regional muscle oxygenation saturation in the control knee of subject 7 across 7 sessions


Subject8T-Session 1
rSO2
0
10
20
30
40
50
60
70
80
90
0 4 8 12 16 20 24 28 32 36 40 44 48
Time (sec)
VL
VM


Subject8T-Session 2
rSO2
0
10
20
30
40
50
60
70
80
90
0 4 8 12 16 20 24 28 32 36 40 44 48 52
Time (sec)
VL
VM


Subject8T-Session 3
rSO2
0
10
20
30
40
50
60
70
80
90
0 4 8 12 16 20 24 28 32 36 40 44 48 52 56 60
Time (sec)
VL
VM


Subject8T-Session 4
rSO2
0
10
20
30
40
50
60
70
80
90
0 4 8 12 16 20 24 28 32 36 40 44 48 52 56 60
Time (sec)
VL
VM

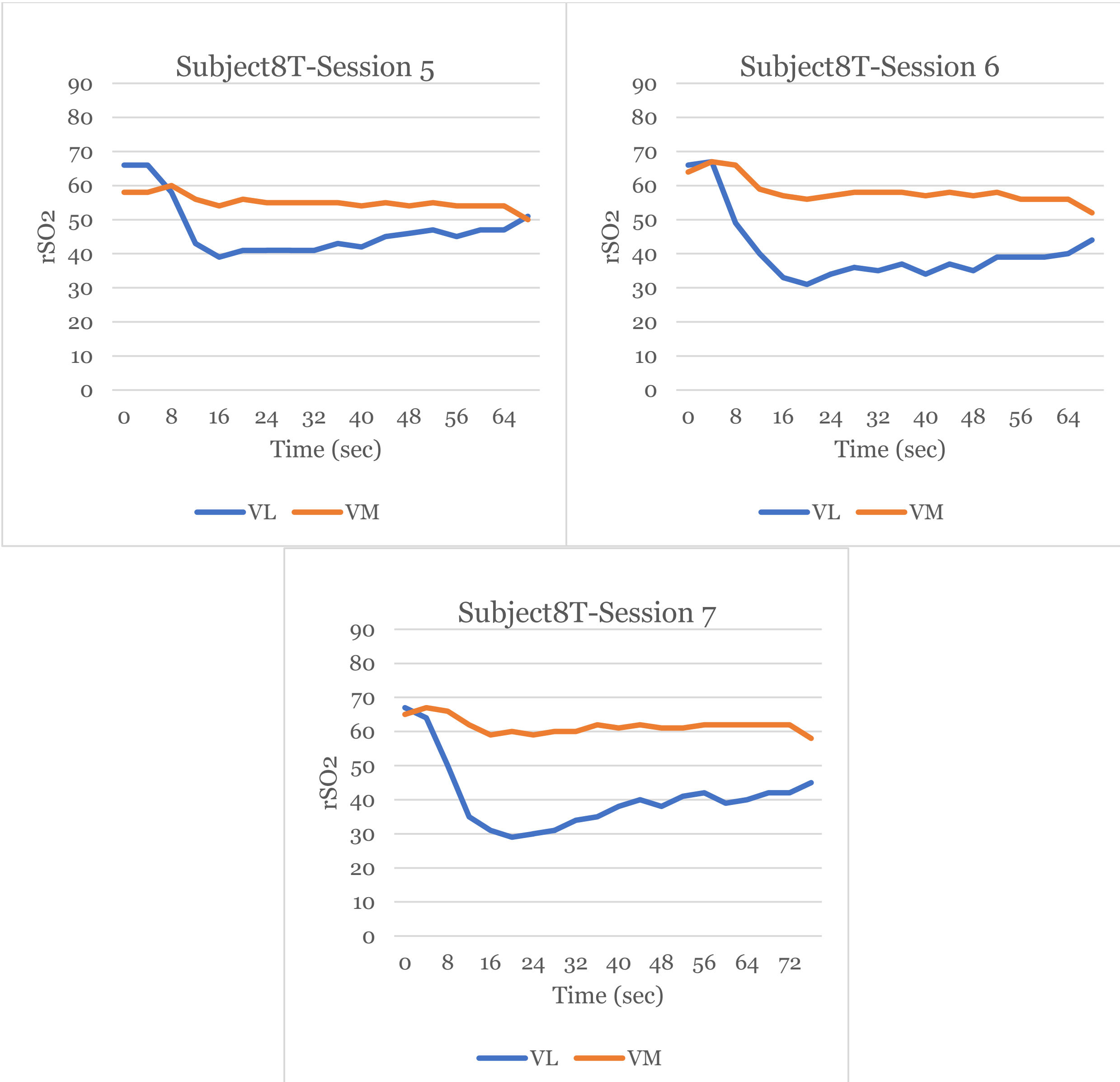
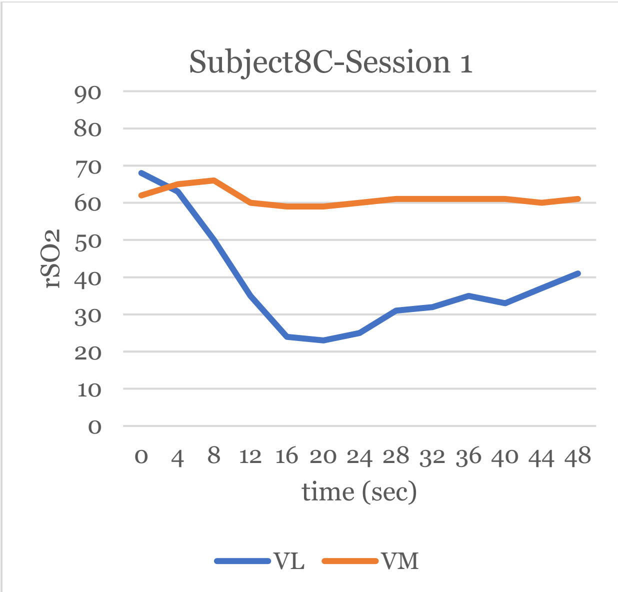
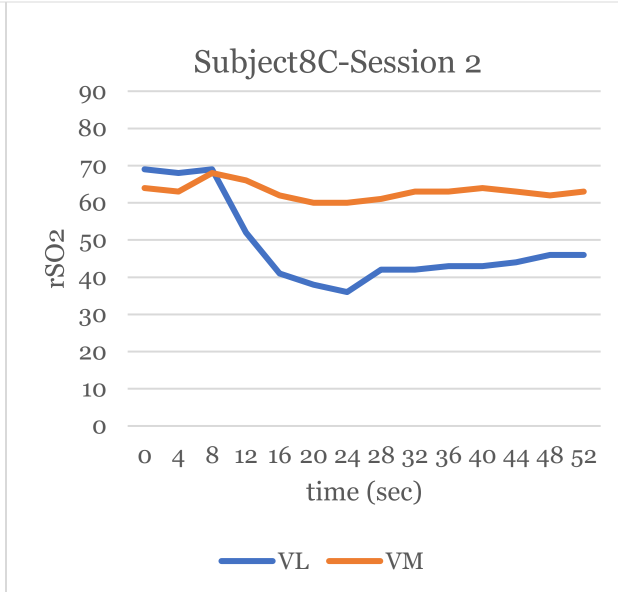
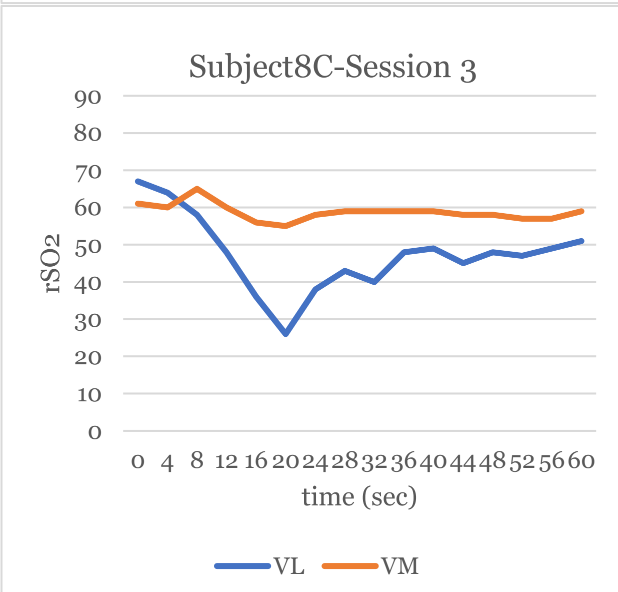
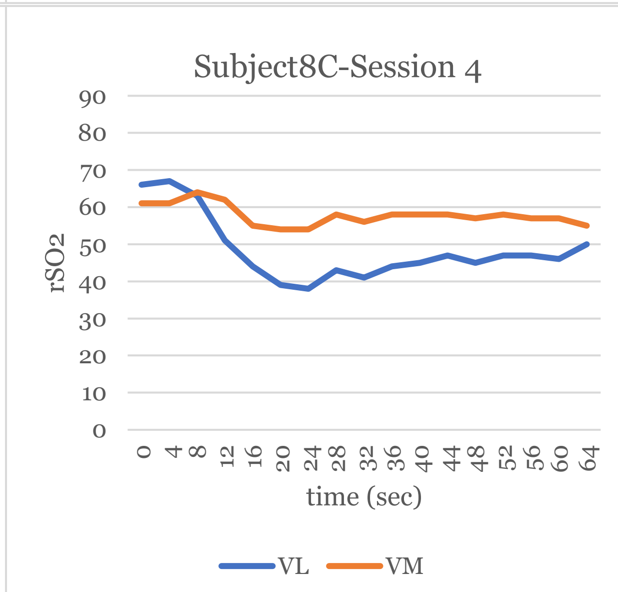


Figure I15: Regional muscle oxygenation saturation in the treatment knee of subject 8 across 7 sessions


Subject8C-Session 1
rSO2
90
80
70
60
50
40
30
20
10
0
0 4 8 12 16 20 24 28 32 36 40 44 48
time (sec)
VL
VM


Subject8C-Session 2
rSO2
90
80
70
60
50
40
30
20
10
0
0 4 8 12 16 20 24 28 32 36 40 44 48 52
time (sec)
VL
VM


Subject8C-Session 3
rSO2
90
80
70
60
50
40
30
20
10
0
0 4 8 12 16 20 24 28 32 36 40 44 48 52 56 60
time (sec)
VL
VM


Subject8C-Session 4
rSO2
90
80
70
60
50
40
30
20
10
0
0 4 8 12 16 20 24 28 32 36 40 44 48 52 56 60 64
time (sec)
VL
VM

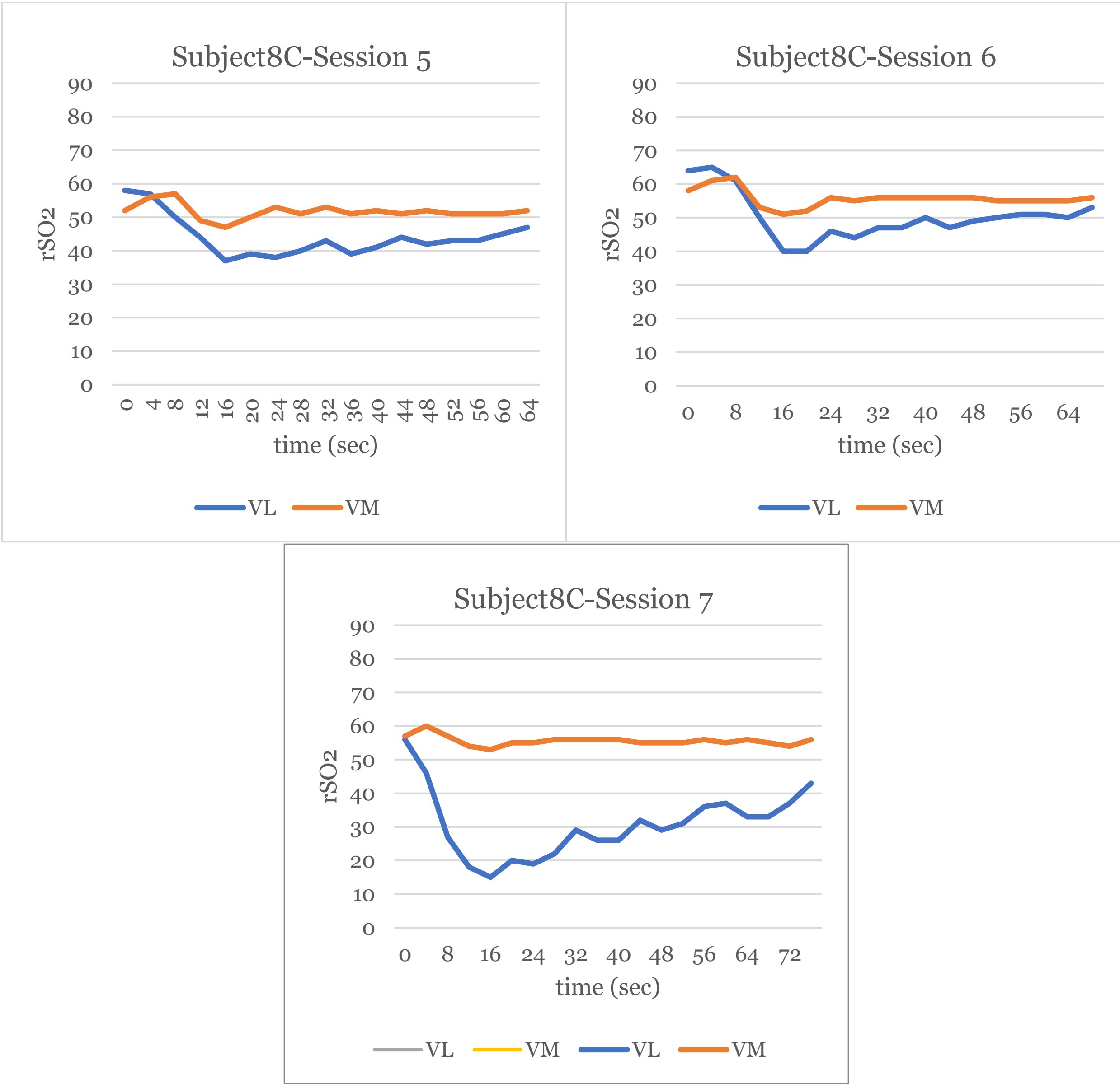
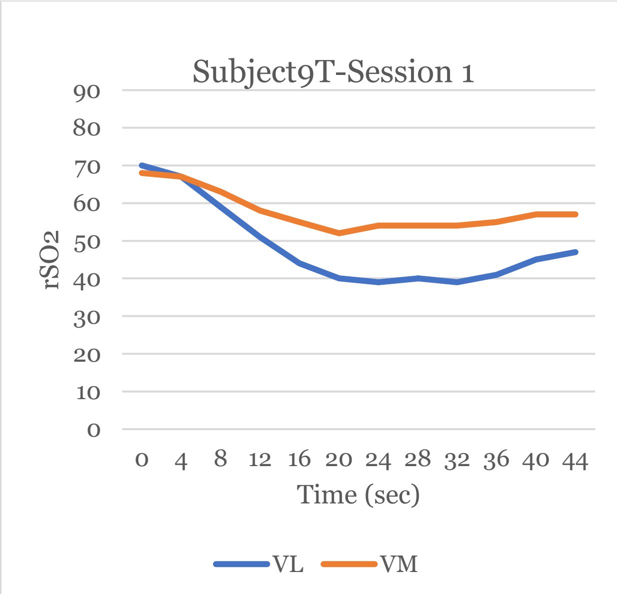
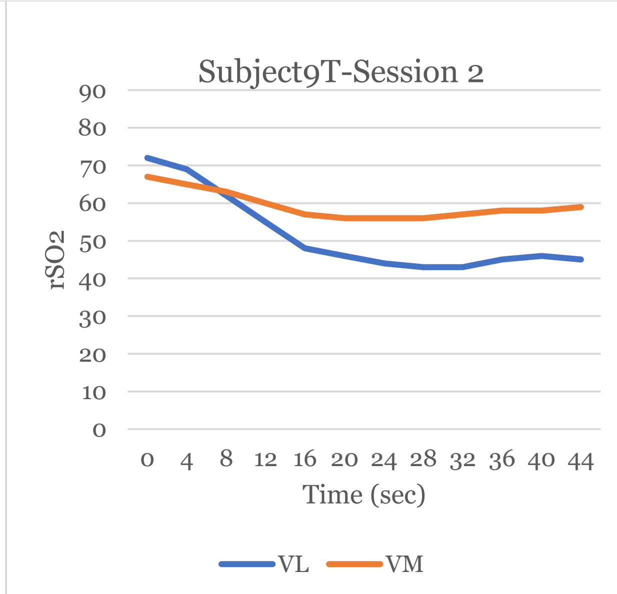
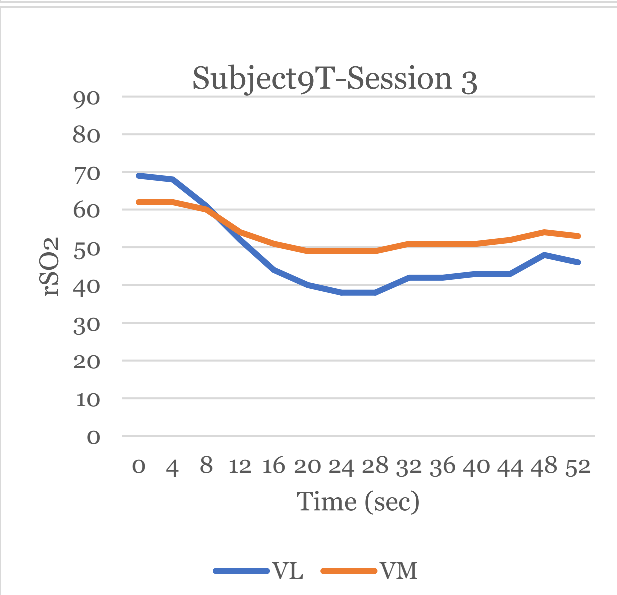
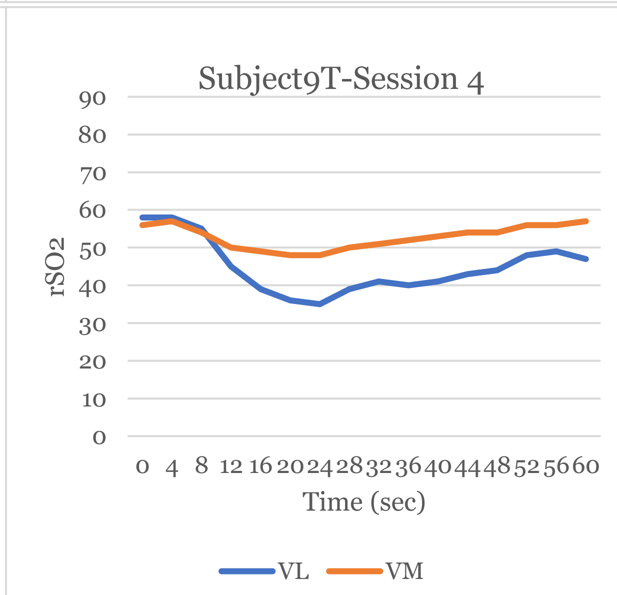


Figure I16: Regional muscle oxygenation saturation in the control knee of subject 8 across 7 sessions


Subject9T-Session 1
rSO2
90
80
70
60
50
40
30
20
10
0
0 4 8 12 16 20 24 28 32 36 40 44
Time (sec)
VL
VM


Subject9T-Session 2
rSO2
90
80
70
60
50
40
30
20
10
0
0 4 8 12 16 20 24 28 32 36 40 44
Time (sec)
VL
VM


Subject9T-Session 3
rSO2
90
80
70
60
50
40
30
20
10
0
0 4 8 12 16 20 24 28 32 36 40 44 48 52
Time (sec)
VL
VM


Subject9T-Session 4
rSO2
90
80
70
60
50
40
30
20
10
0
0 4 8 12 16 20 24 28 32 36 40 44 48 52 56 60
Time (sec)
VL
VM

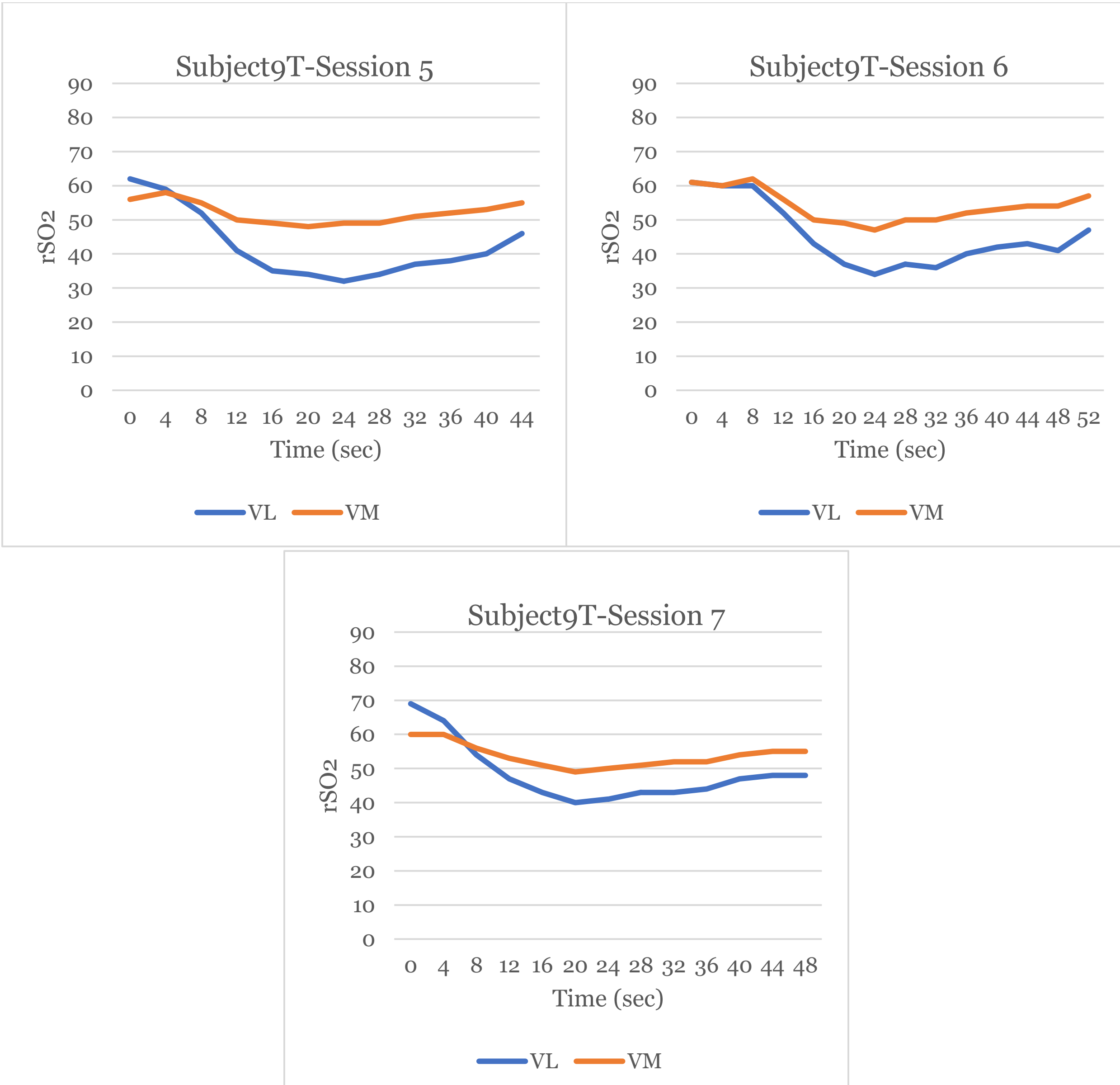
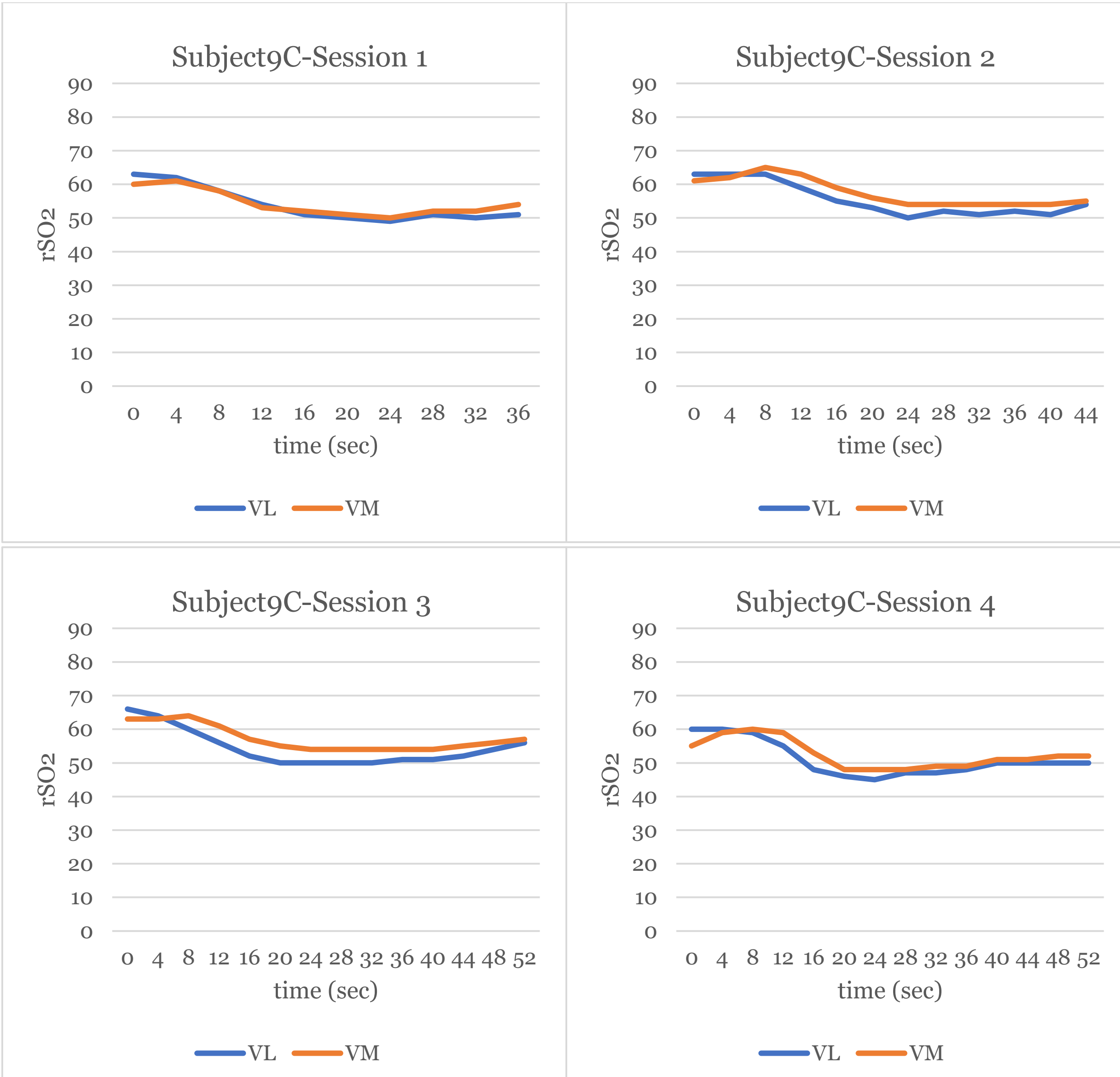
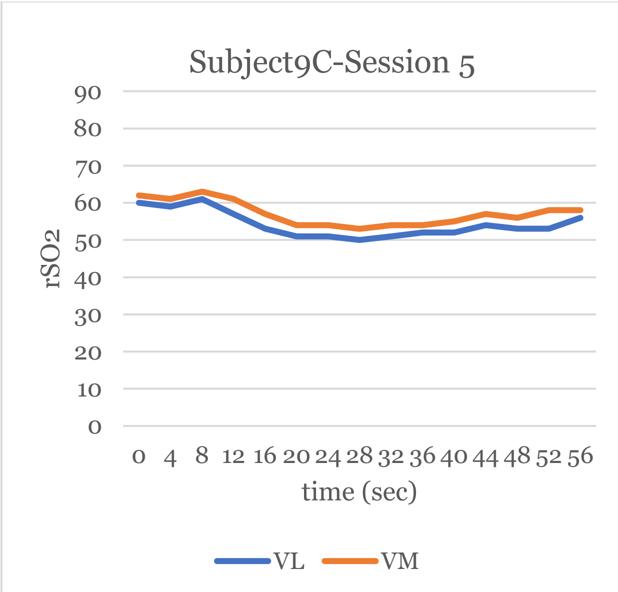
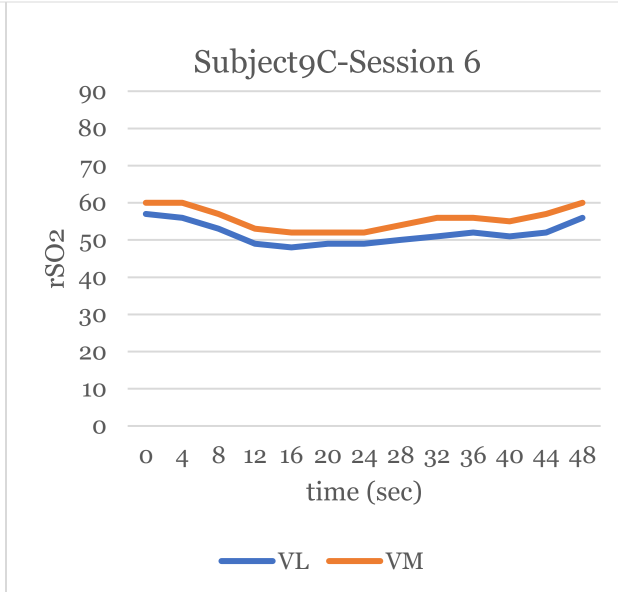


Figure I17: Regional muscle oxygenation saturation in the treatment knee of subject 9 across 7 sessions


Subject9C-Session 1
rSO2
90
80
70
60
50
40
30
20
10
0
0 4 8 12 16 20 24 28 32 36
time (sec)
VL
VM
Subject9C-Session 2
rSO2
90
80
70
60
50
40
30
20
10
0
0 4 8 12 16 20 24 28 32 36 40 44
time (sec)
VL
VM
Subject9C-Session 3
rSO2
90
80
70
60
50
40
30
20
10
0
0 4 8 12 16 20 24 28 32 36 40 44 48 52
time (sec)
VL
VM
Subject9C-Session 4
rSO2
90
80
70
60
50
40
30
20
10
0
0 4 8 12 16 20 24 28 32 36 40 44 48 52
time (sec)
VL
VM





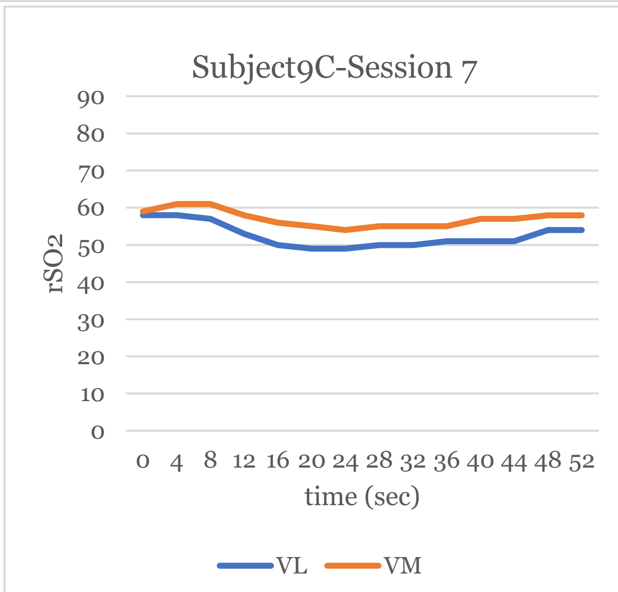
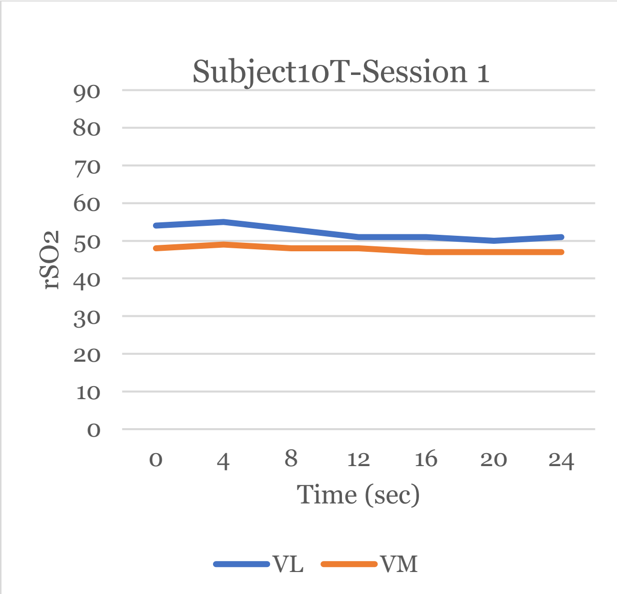
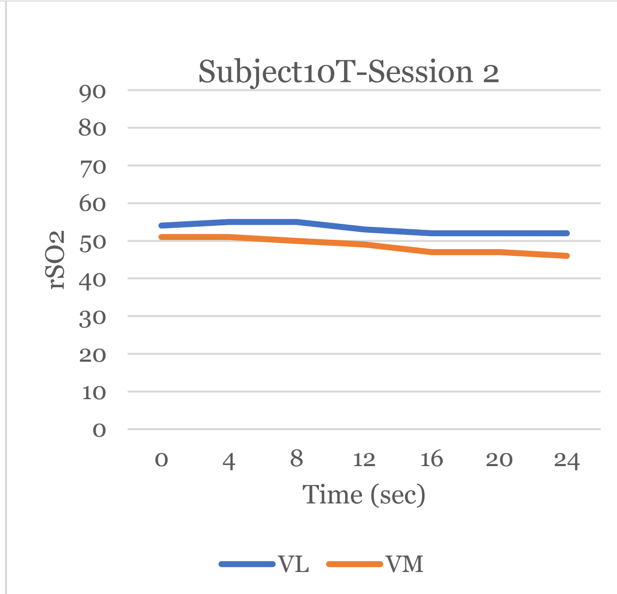
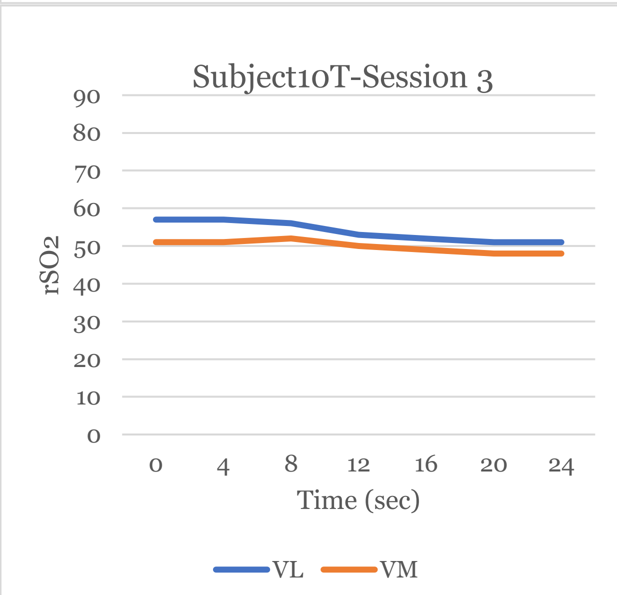
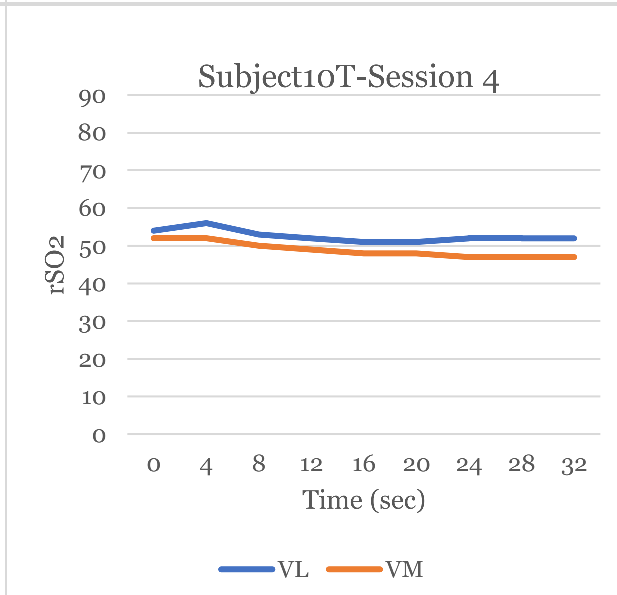


Figure I18: Regional muscle oxygenation saturation in the control knee of subject 9 across 7 sessions


Subject10T-Session 1
rSO2
90
80
70
60
50
40
30
20
10
0
0
4
8
12
16
20
24
Time (sec)
VL
VM


Subject10T-Session 2
rSO2
90
80
70
60
50
40
30
20
10
0
0
4
8
12
16
20
24
Time (sec)
VL
VM


Subject10T-Session 3
rSO2
90
80
70
60
50
40
30
20
10
0
0
4
8
12
16
20
24
Time (sec)
VL
VM


Subject10T-Session 4
rSO2
90
80
70
60
50
40
30
20
10
0
0
4
8
12
16
20
24
28
32
Time (sec)
VL
VM

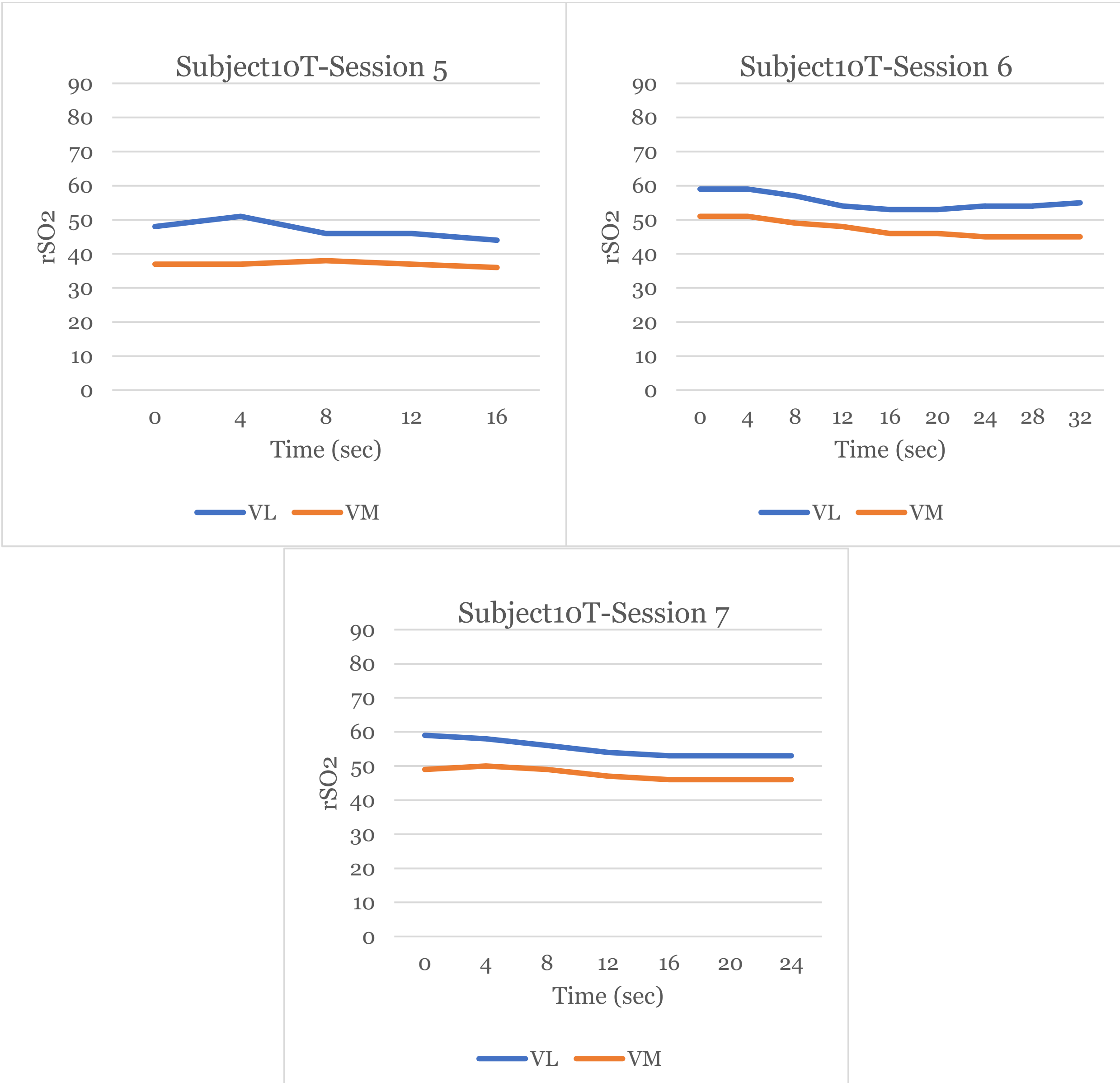
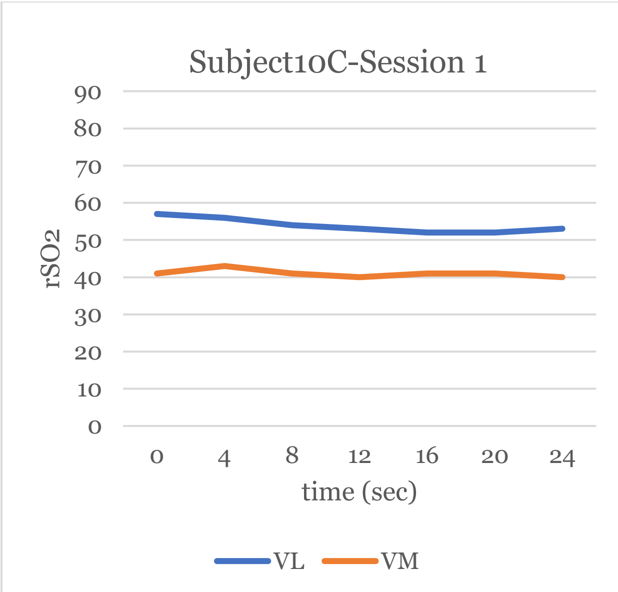
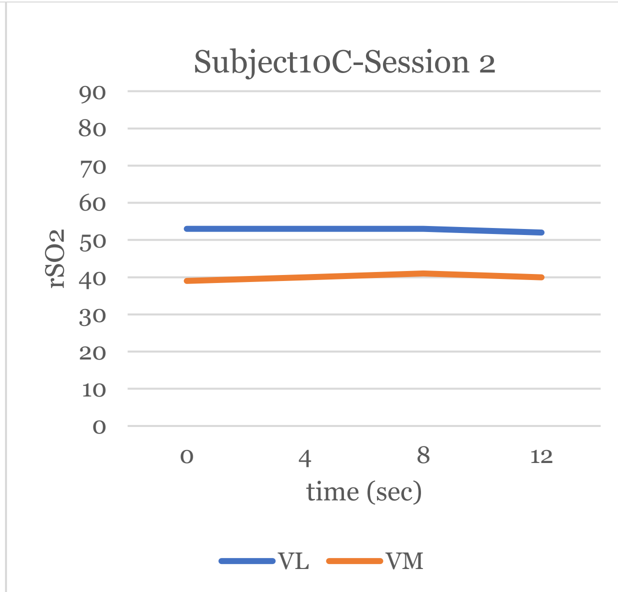
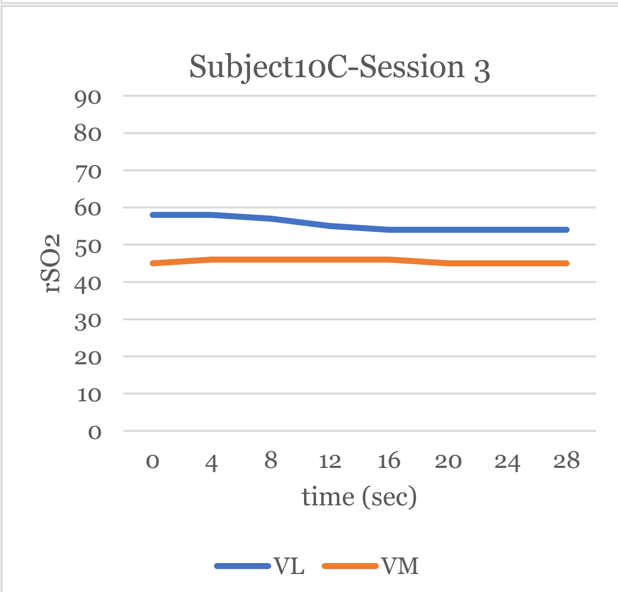
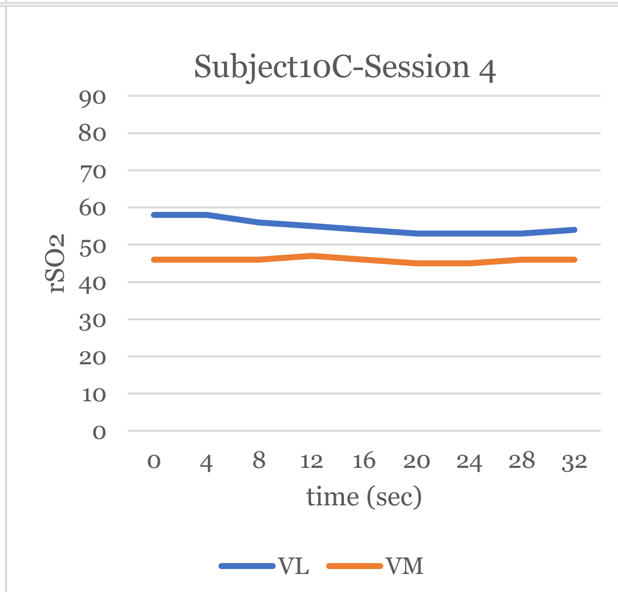


Figure I19: Regional muscle oxygenation saturation in the treatment knee of subject 10 across 7 sessions


Subject10C-Session 1
90
80
70
60
50
40
30
20
10
0
rSO2
0
4
8
12
16
20
24
time (sec)
VL
VM


Subject10C-Session 2
90
80
70
60
50
40
30
20
10
0
rSO2
0
4
8
12
time (sec)
VL
VM


Subject10C-Session 3
90
80
70
60
50
40
30
20
10
0
rSO2
0
4
8
12
16
20
24
28
time (sec)
VL
VM


Subject10C-Session 4
90
80
70
60
50
40
30
20
10
0
rSO2
0
4
8
12
16
20
24
28
32
time (sec)
VL
VM

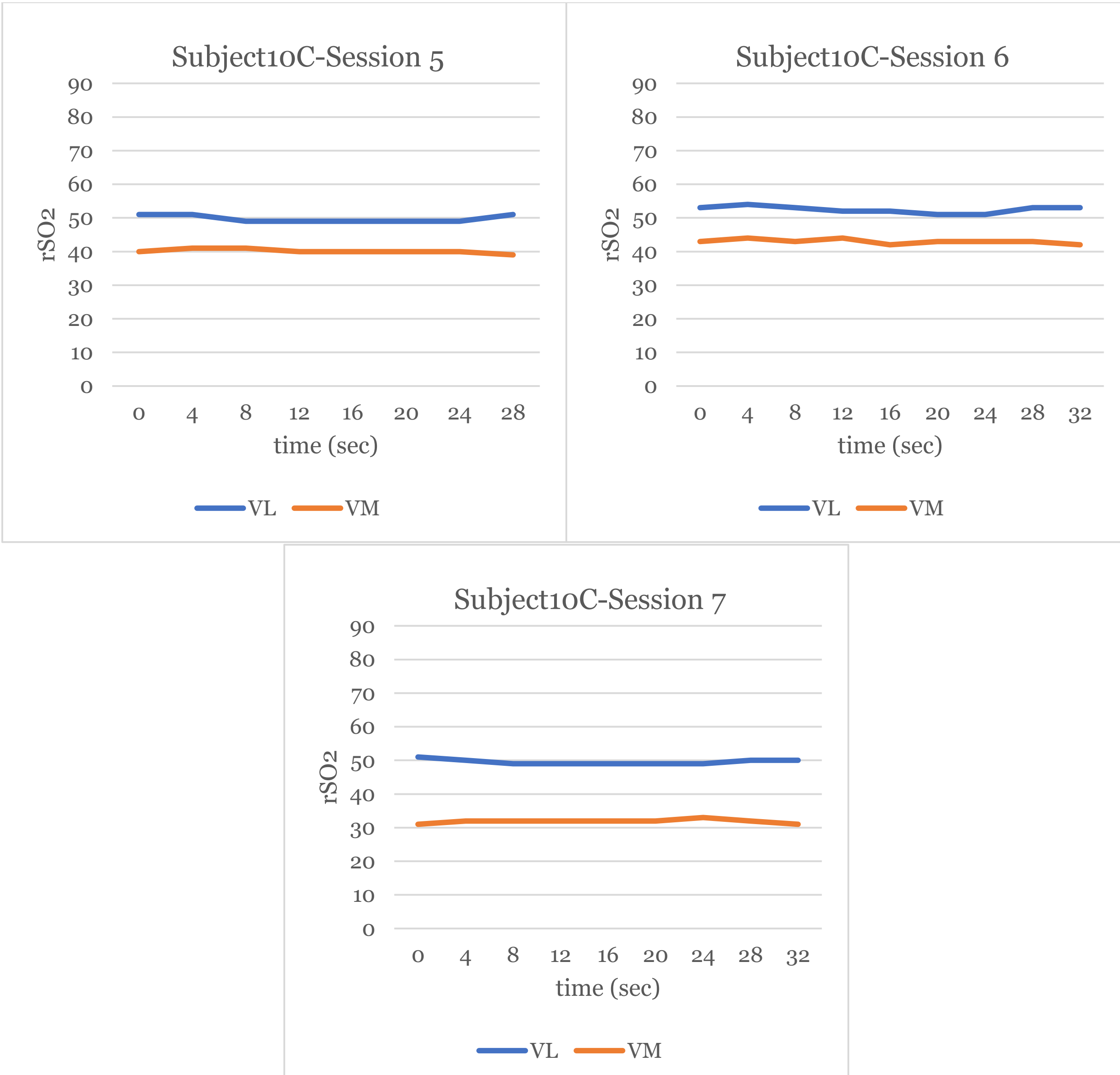
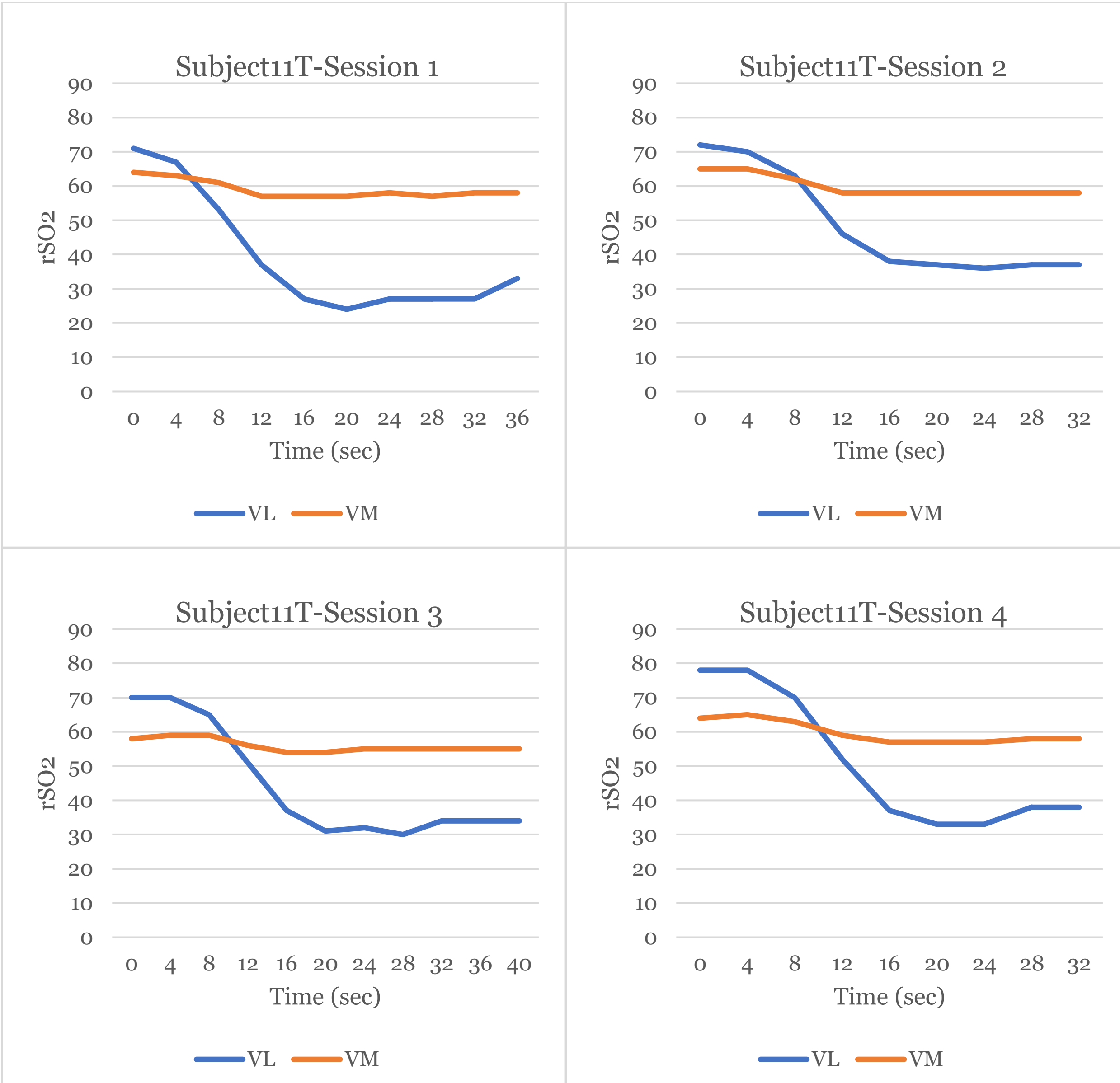


Figure I20: Regional muscle oxygenation saturation in the control knee of subject s10 across 7 sessions



Subject11T-Session 1
rSO2
0 10 20 30 40 50 60 70 80 90
0 4 8 12 16 20 24 28 32 36
Time (sec)
VL VM
Subject11T-Session 2
rSO2
0 10 20 30 40 50 60 70 80 90
0 4 8 12 16 20 24 28 32
Time (sec)
VL VM
Subject11T-Session 3
rSO2
0 10 20 30 40 50 60 70 80 90
0 4 8 12 16 20 24 28 32 36 40
Time (sec)
VL VM
Subject11T-Session 4
rSO2
0 10 20 30 40 50 60 70 80 90
0 4 8 12 16 20 24 28 32
Time (sec)
VL VM

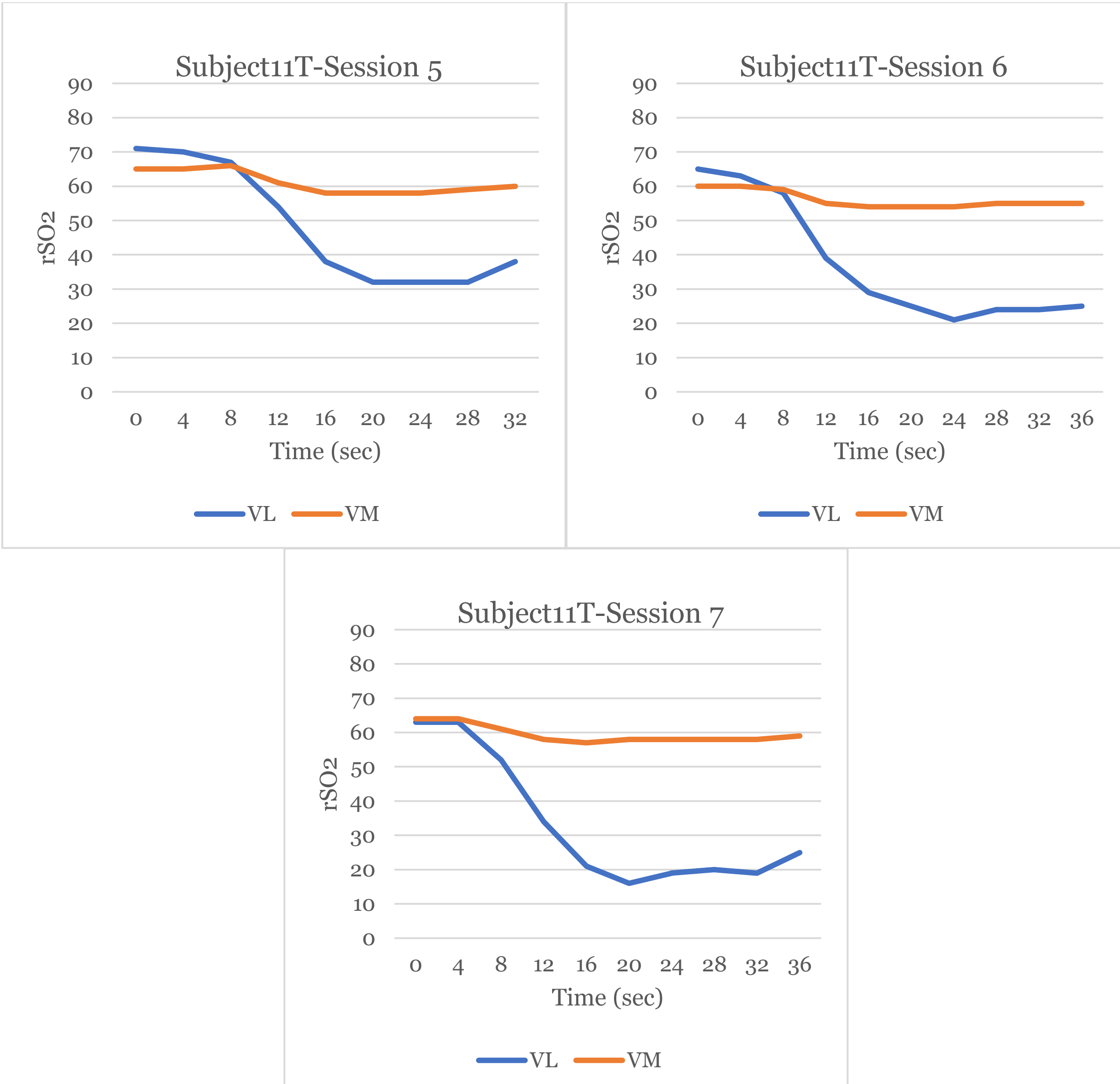
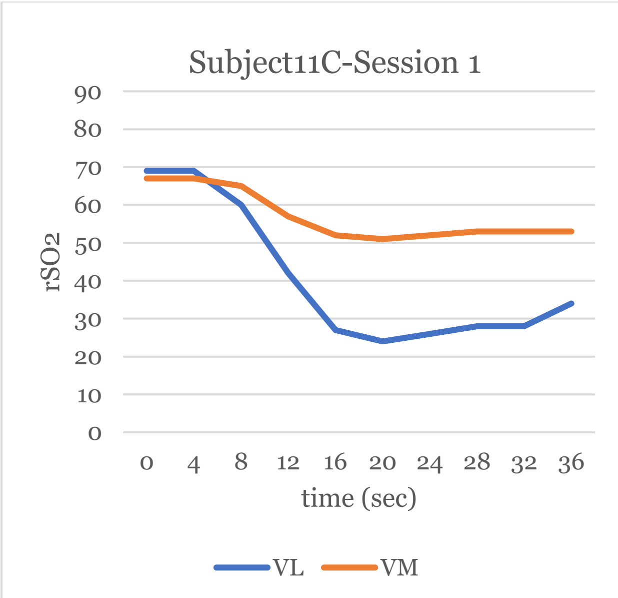
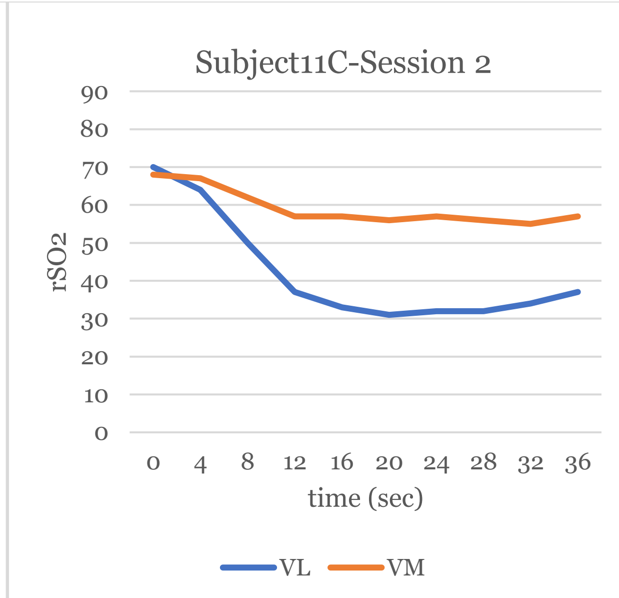
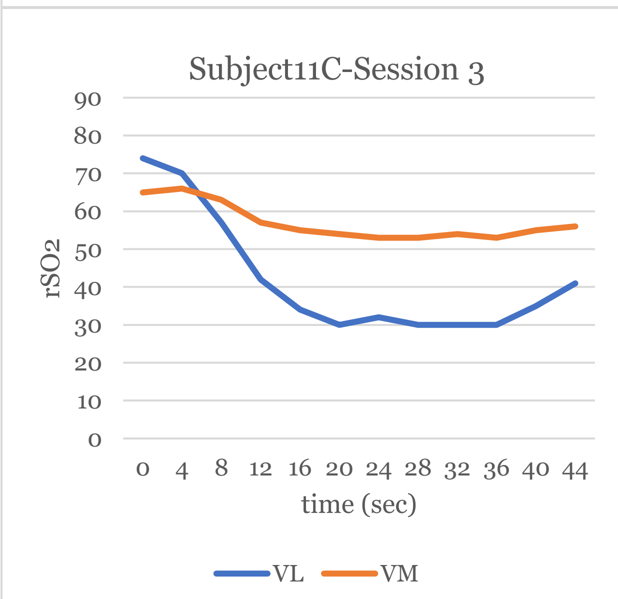
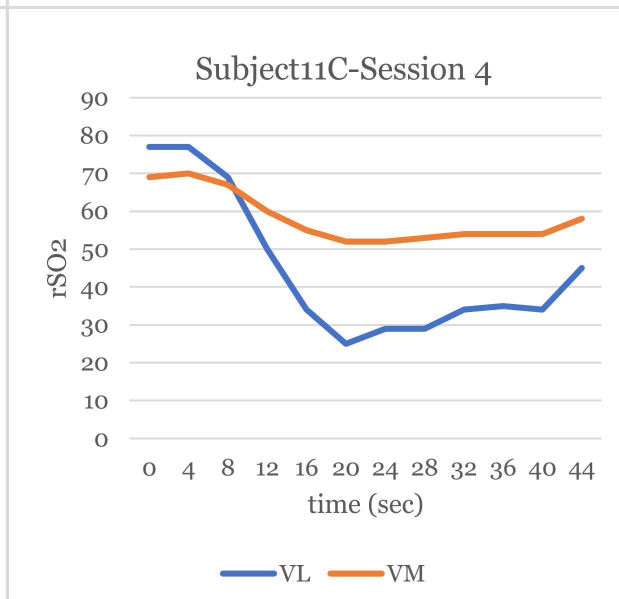
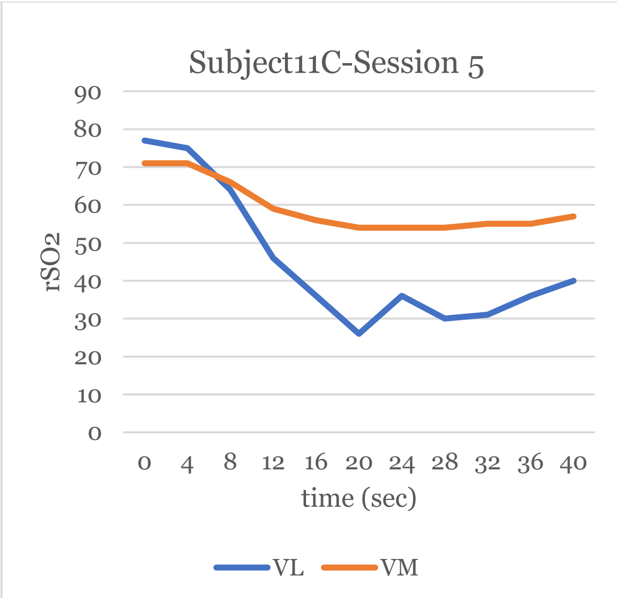
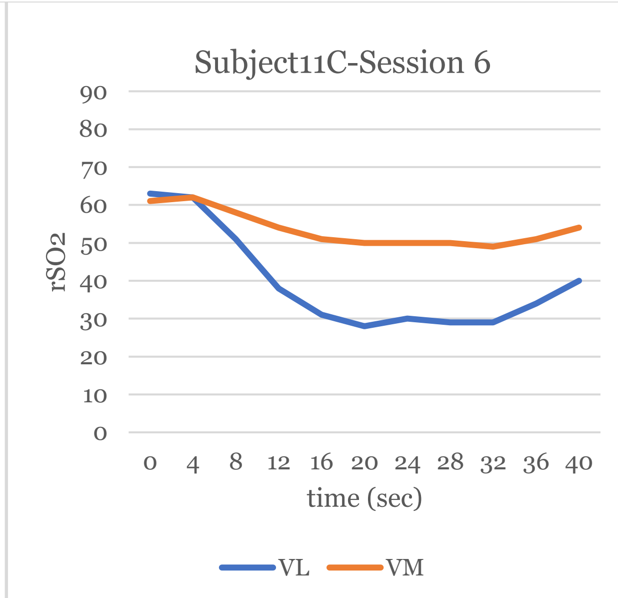


Figure I21: Regional muscle oxygenation saturation in the treatment knee of subject s11 across 7 sessions


Subject11C-Session 1
rSO2
0
10
20
30
40
50
60
70
80
90
0 4 8 12 16 20 24 28 32 36
time (sec)
VL
VM

Subject11C-Session 2
rSO2
0
10
20
30
40
50
60
70
80
90
0 4 8 12 16 20 24 28 32 36
time (sec)
VL
VM

Subject11C-Session 3
rSO2
0
10
20
30
40
50
60
70
80
90
0 4 8 12 16 20 24 28 32 36 40 44
time (sec)
VL
VM

Subject11C-Session 4
rSO2
0
10
20
30
40
50
60
70
80
90
0 4 8 12 16 20 24 28 32 36 40 44
time (sec)
VL
VM





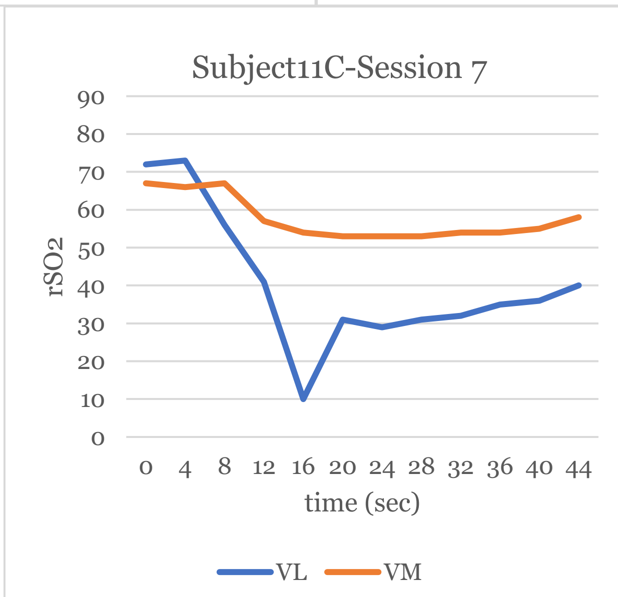


Figure I22: Regional muscle oxygenation saturation in the control knee of subject s11 across 7 sessions


Subject12T-Session 1
rSO2
90
80
70
60
50
40
30
20
10
0
0 4 8 12 16 20 24 28 32 36 40 44 48 52
Time (sec)
VL
VM
Subject12T-Session 2
rSO2
90
80
70
60
50
40
30
20
10
0
0 4 8 12 16 20 24 28 32 36 40 44 48 52
Time (sec)
VL
VM
Subject12T-Session 3
rSO2
90
80
70
60
50
40
30
20
10
0
0 4 8 12 16 20
Time (sec)
VL
VM
Subject12T-Session 4
rSO2
90
80
70
60
50
40
30
20
10
0
0 4 8 12 16 20 24
Time (sec)
VL
VM

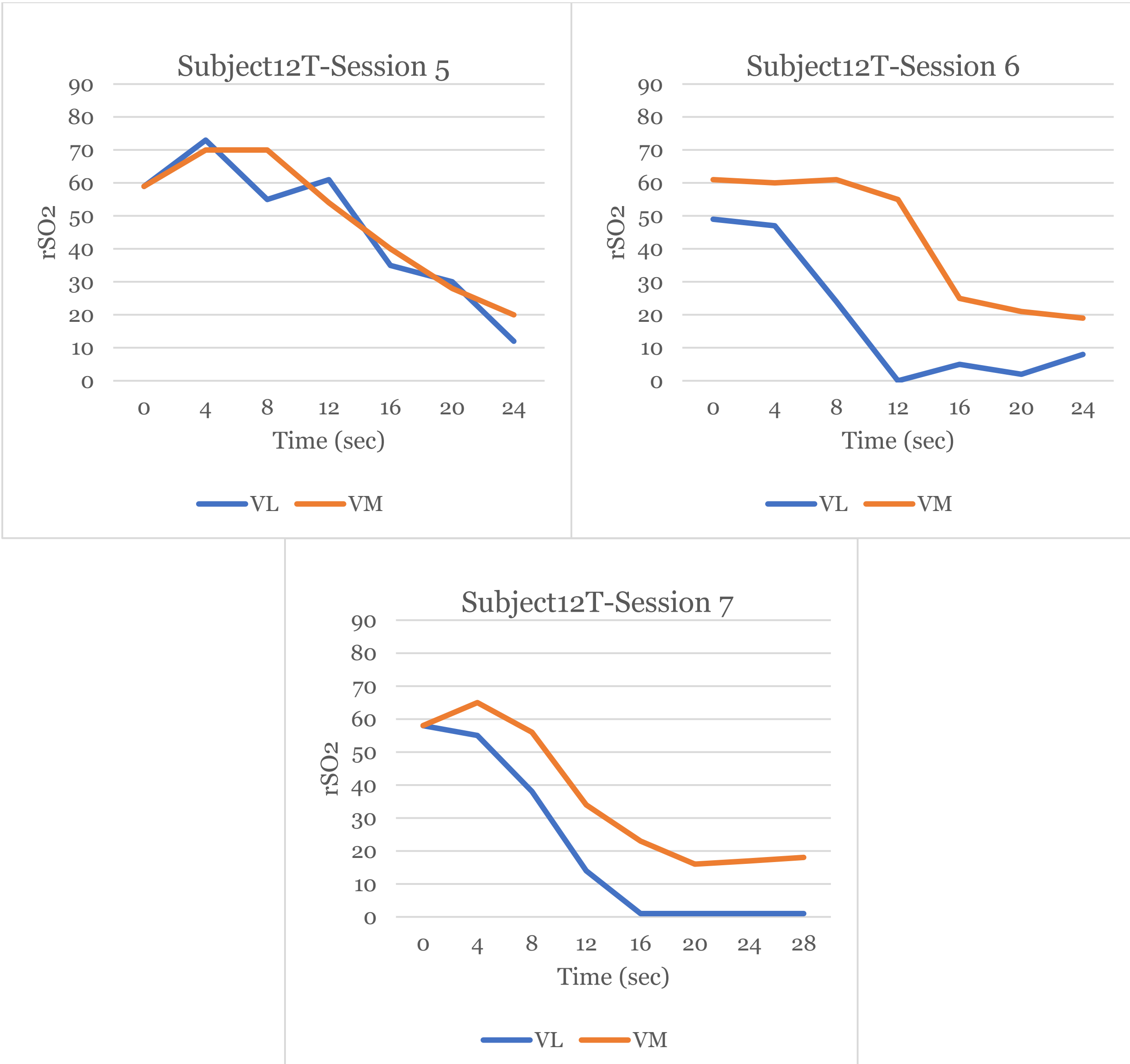
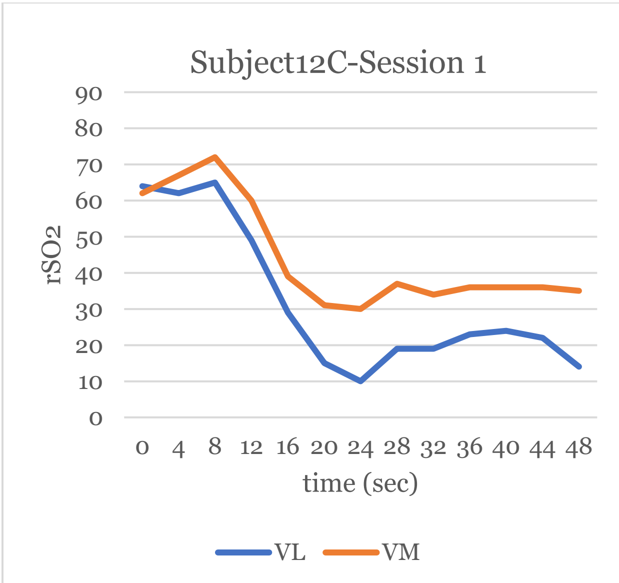
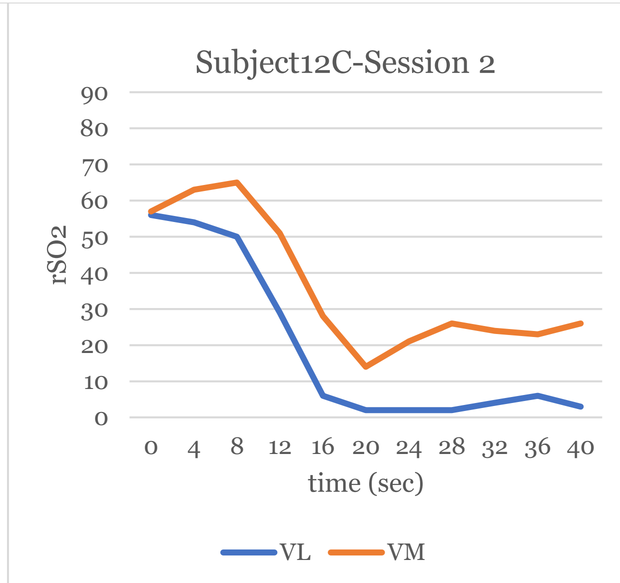
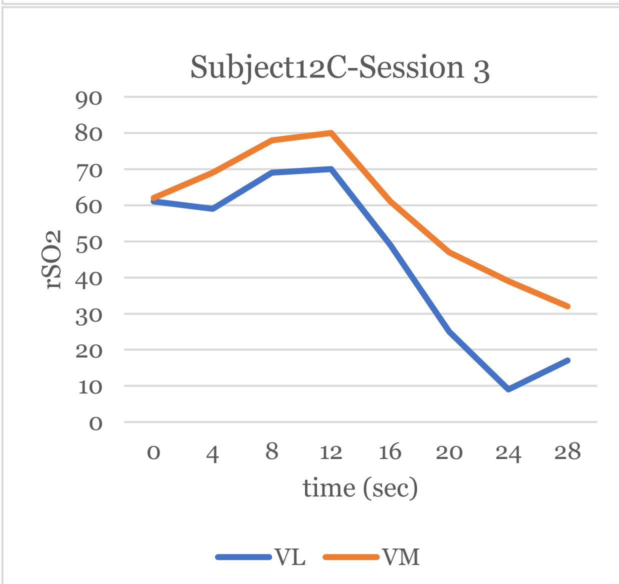
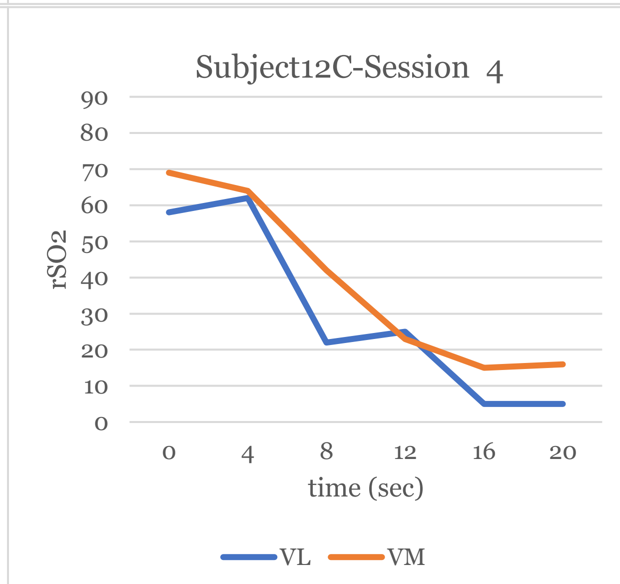


Figure I23: Regional muscle oxygenation saturation in the treatment knee of subject s12 across 7 sessions


Subject12C-Session 1
rSO2
90
80
70
60
50
40
30
20
10
0
0 4 8 12 16 20 24 28 32 36 40 44 48
time (sec)
VL
VM


Subject12C-Session 2
rSO2
90
80
70
60
50
40
30
20
10
0
0 4 8 12 16 20 24 28 32 36 40
time (sec)
VL
VM


Subject12C-Session 3
rSO2
90
80
70
60
50
40
30
20
10
0
0 4 8 12 16 20 24 28
time (sec)
VL
VM


Subject12C-Session 4
rSO2
90
80
70
60
50
40
30
20
10
0
0 4 8 12 16 20
time (sec)
VL
VM

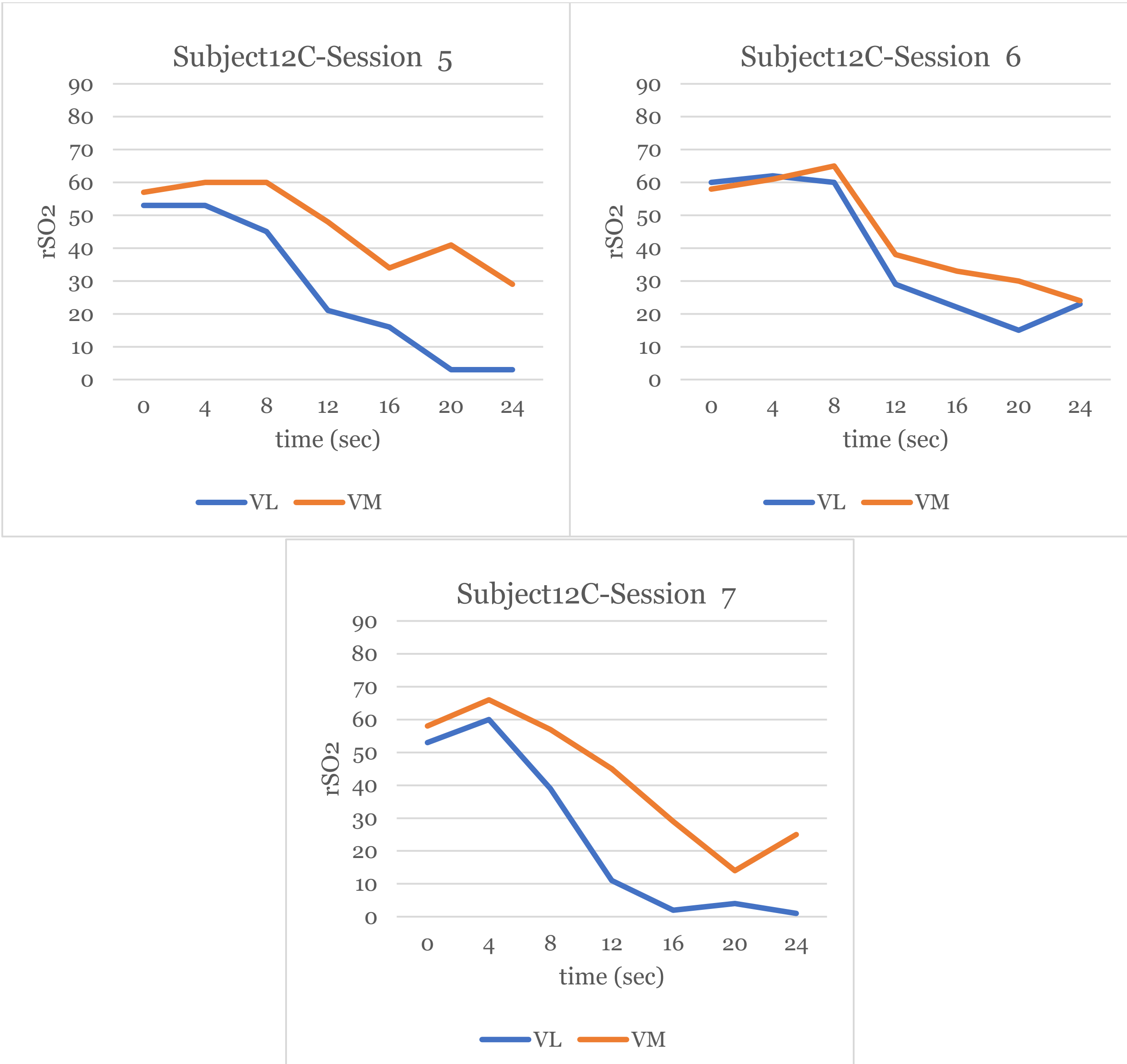
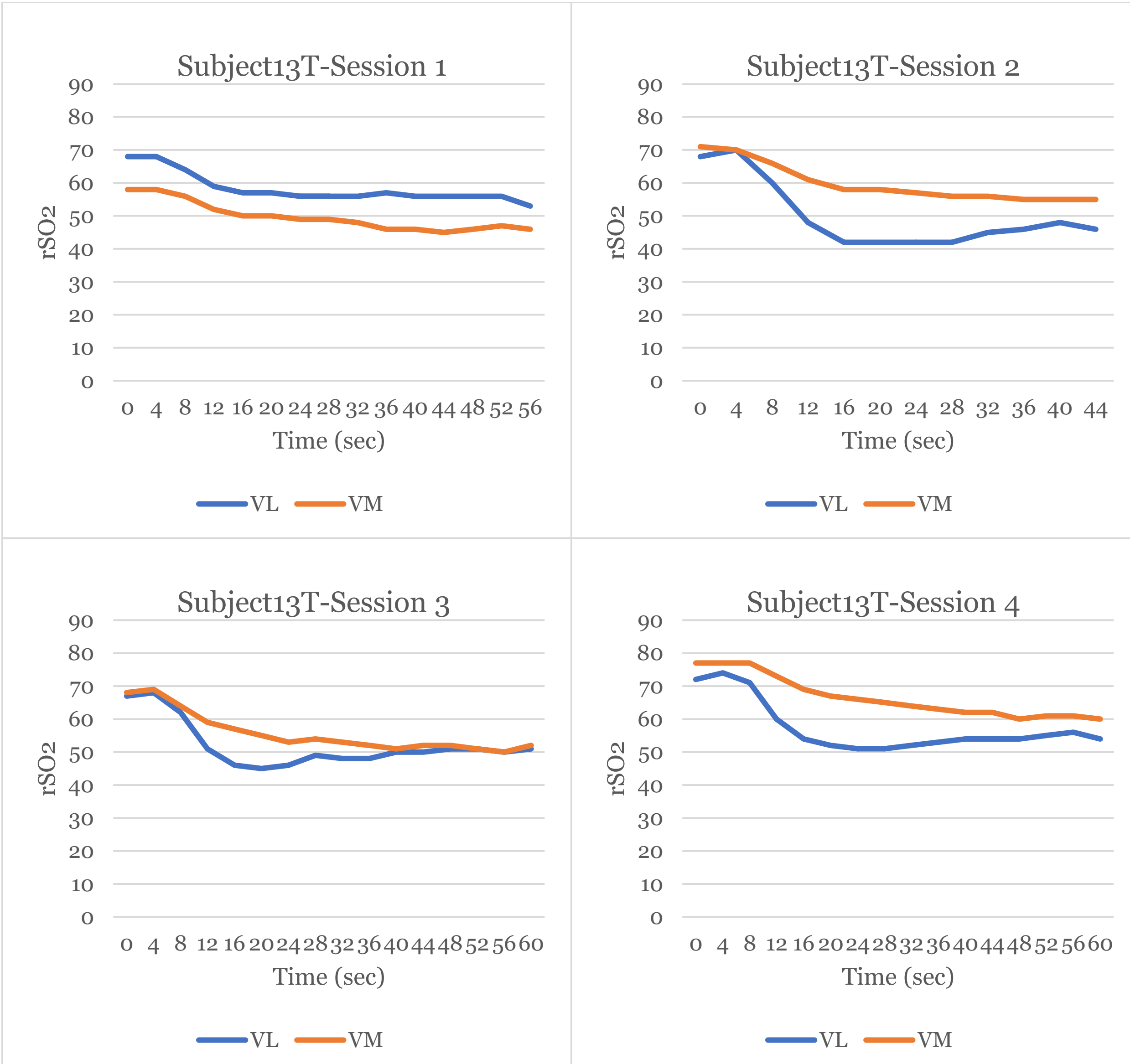


Figure I24: Regional muscle oxygenation saturation in the control knee of subject s12 across 7 sessions


Subject13T-Session 1
rSO2
Time (sec)
VL
VM
Subject13T-Session 2
rSO2
Time (sec)
VL
VM
Subject13T-Session 3
rSO2
Time (sec)
VL
VM
Subject13T-Session 4
rSO2
Time (sec)
VL
VM

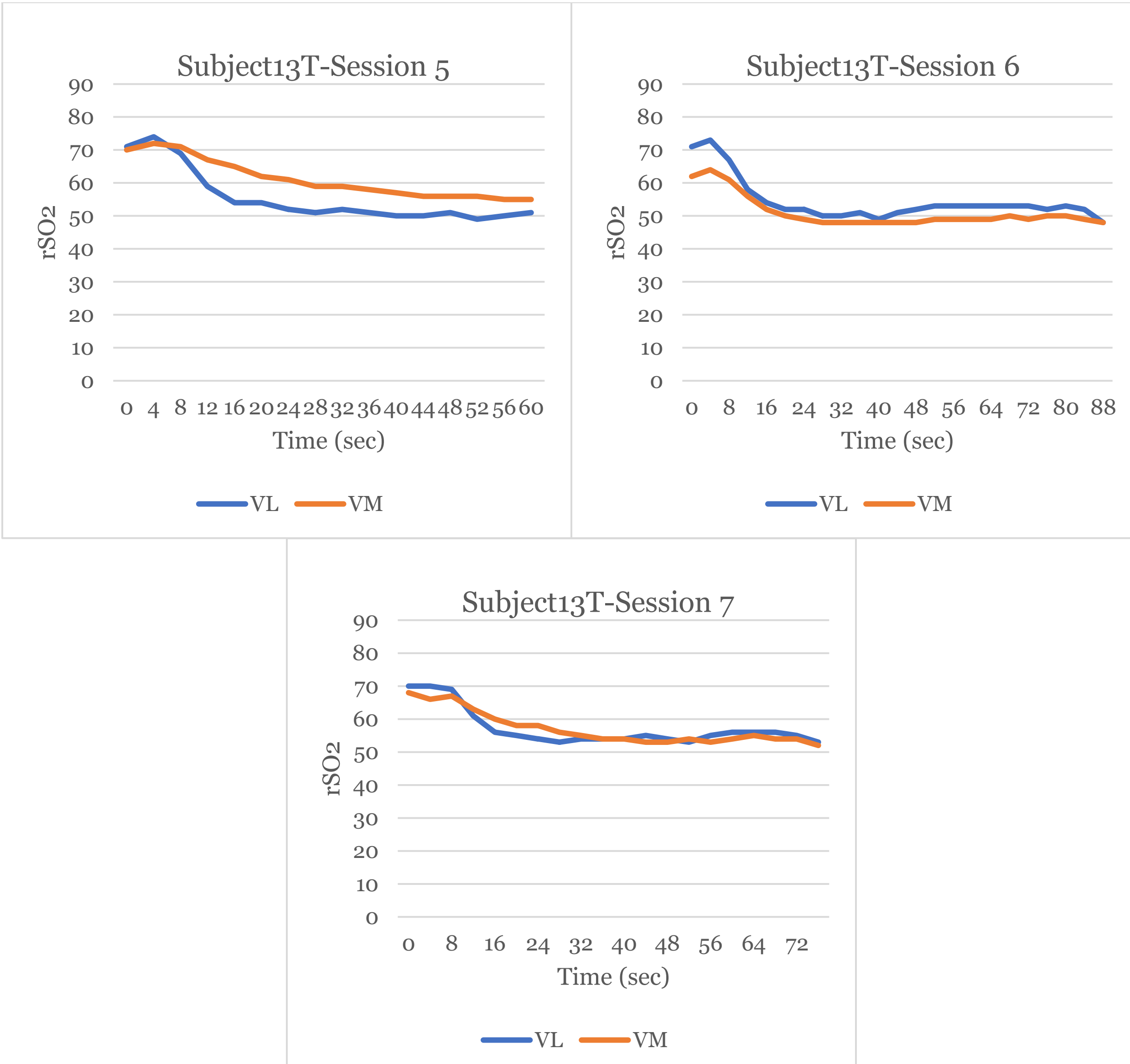
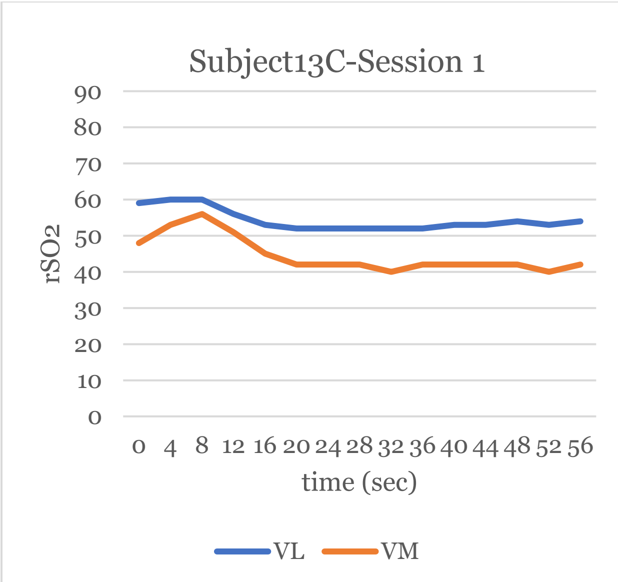
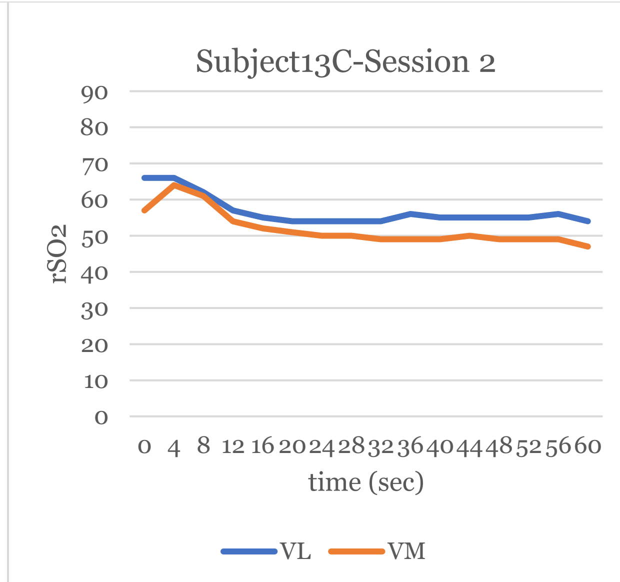
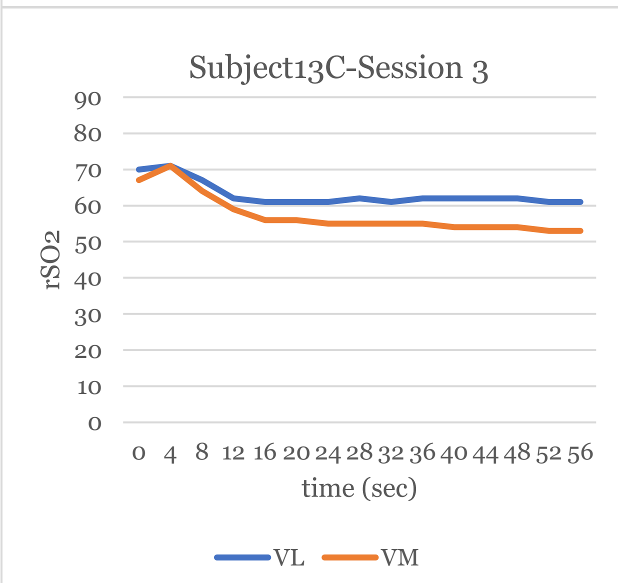
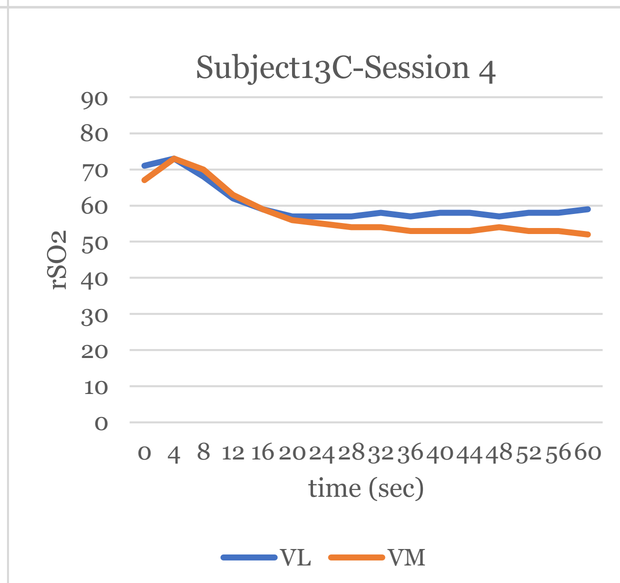


Figure I25: Regional muscle oxygenation saturation in the treatment knee of subject s13 across 7 sessions


Subject13C-Session 1
rSO2
90
80
70
60
50
40
30
20
10
0
0 4 8 12 16 20 24 28 32 36 40 44 48 52 56
time (sec)
VL
VM


Subject13C-Session 2
rSO2
90
80
70
60
50
40
30
20
10
0
0 4 8 12 16 20 24 28 32 36 40 44 48 52 56 60
time (sec)
VL
VM


Subject13C-Session 3
rSO2
90
80
70
60
50
40
30
20
10
0
0 4 8 12 16 20 24 28 32 36 40 44 48 52 56
time (sec)
VL
VM


Subject13C-Session 4
rSO2
90
80
70
60
50
40
30
20
10
0
0 4 8 12 16 20 24 28 32 36 40 44 48 52 56 60
time (sec)
VL
VM

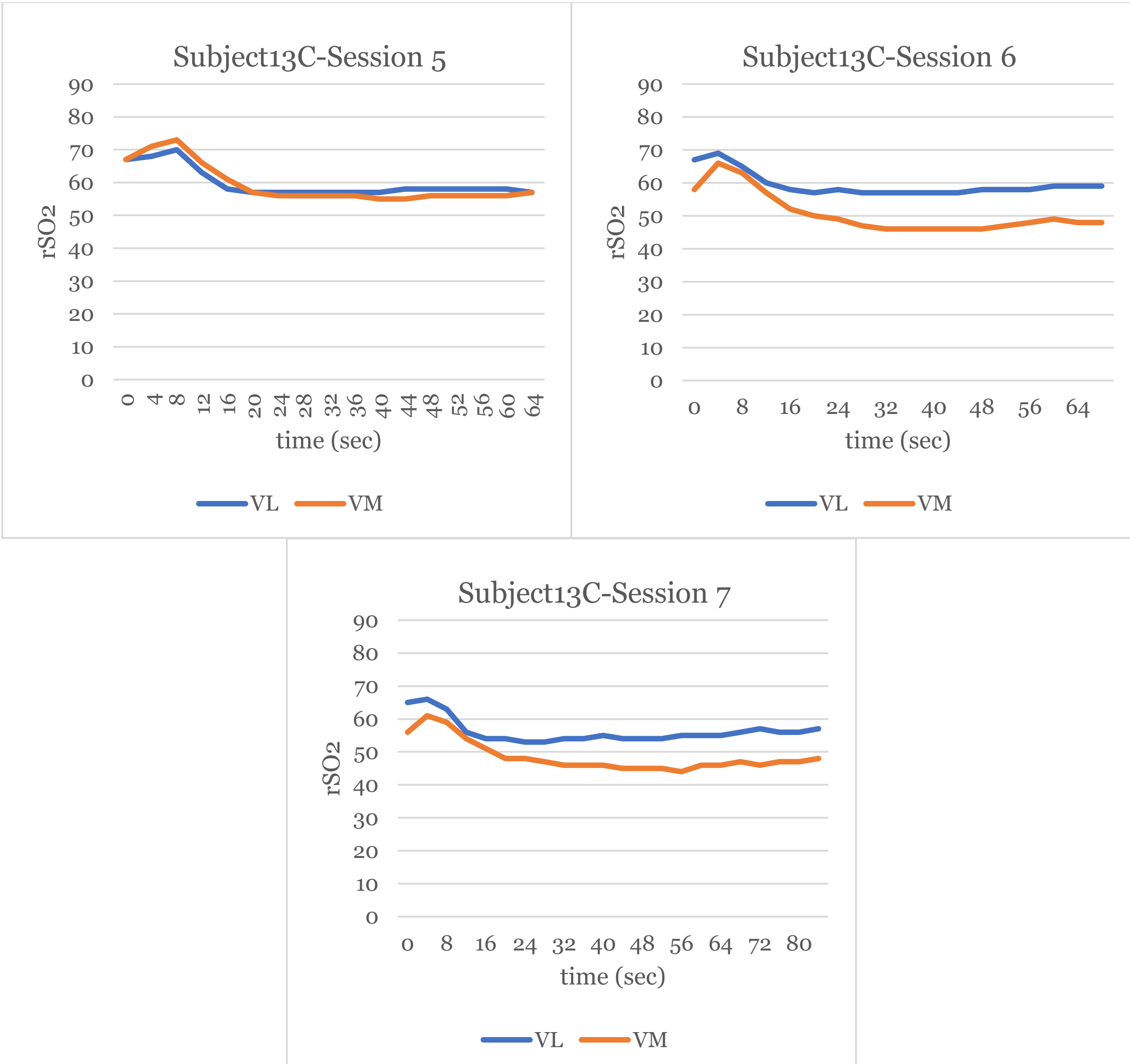
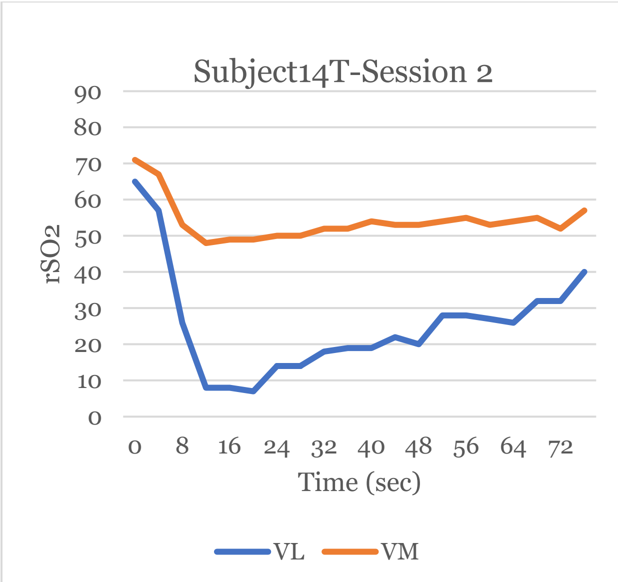
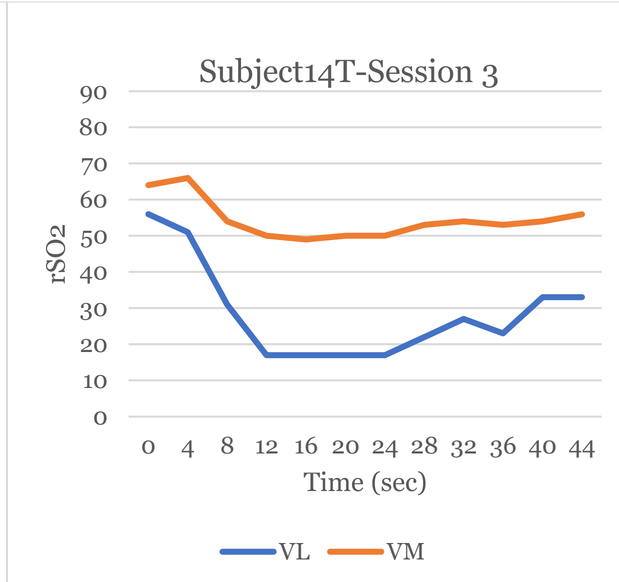
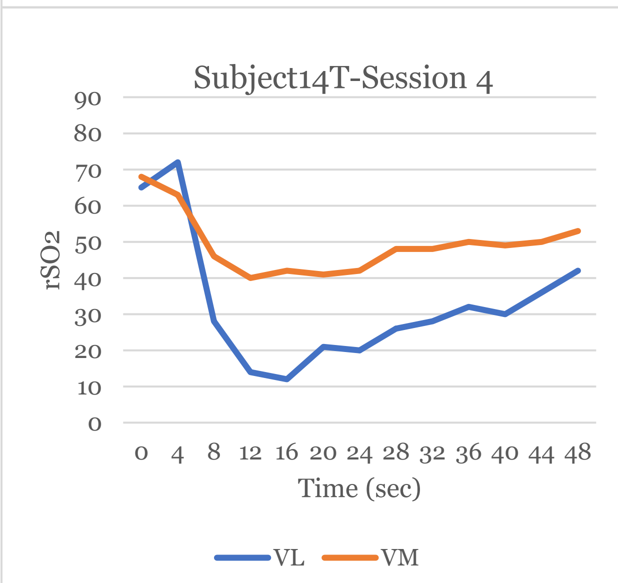
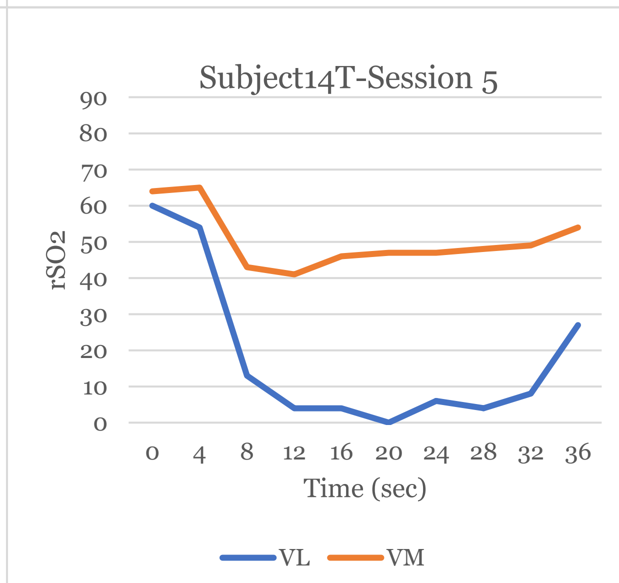


Figure I26: Regional muscle oxygenation saturation in the control knee of subject s13 across 7 sessions


Subject14T-Session 2
rSO2
90
80
70
60
50
40
30
20
10
0
0 8 16 24 32 40 48 56 64 72
Time (sec)
VL
VM


Subject14T-Session 3
rSO2
90
80
70
60
50
40
30
20
10
0
0 4 8 12 16 20 24 28 32 36 40 44
Time (sec)
VL
VM


Subject14T-Session 4
rSO2
90
80
70
60
50
40
30
20
10
0
0 4 8 12 16 20 24 28 32 36 40 44 48
Time (sec)
VL
VM


Subject14T-Session 5
rSO2
90
80
70
60
50
40
30
20
10
0
0 4 8 12 16 20 24 28 32 36
Time (sec)
VL
VM

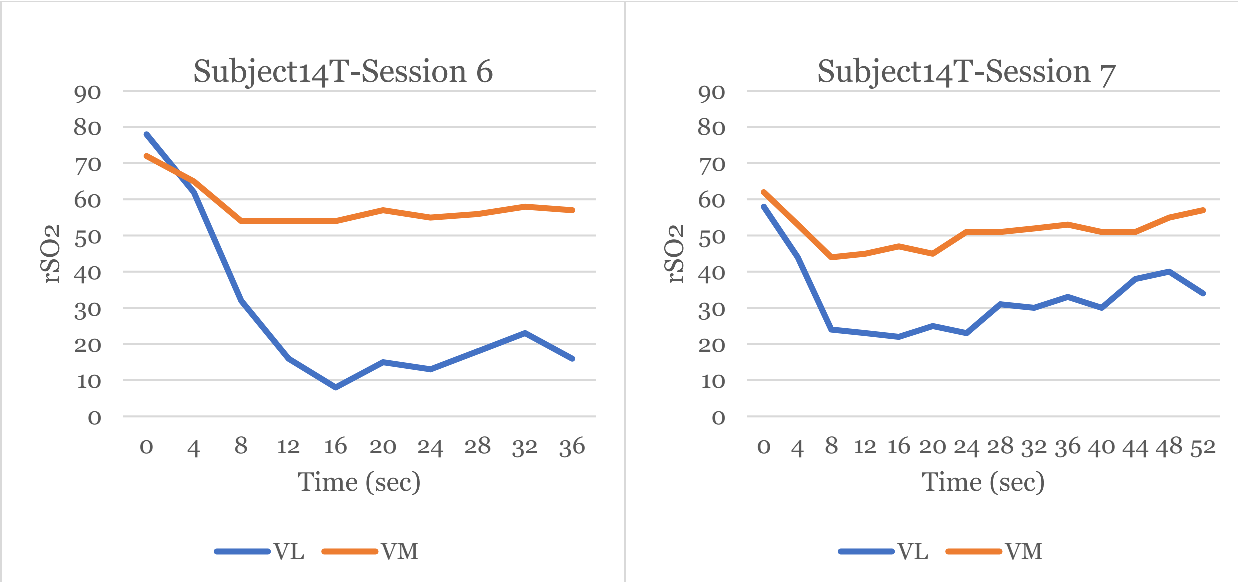
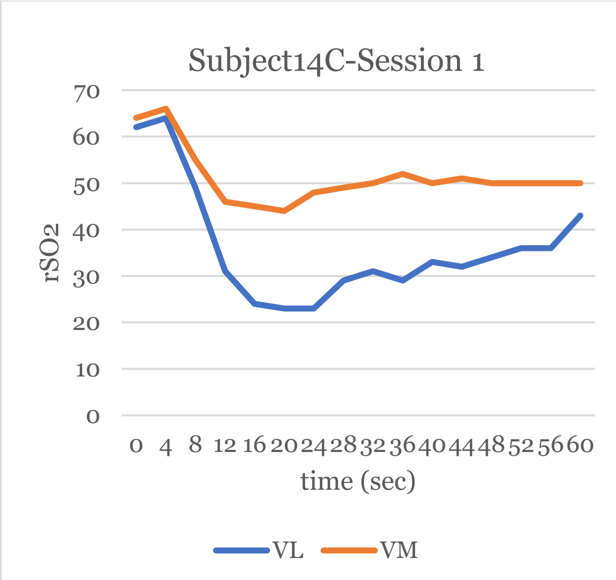
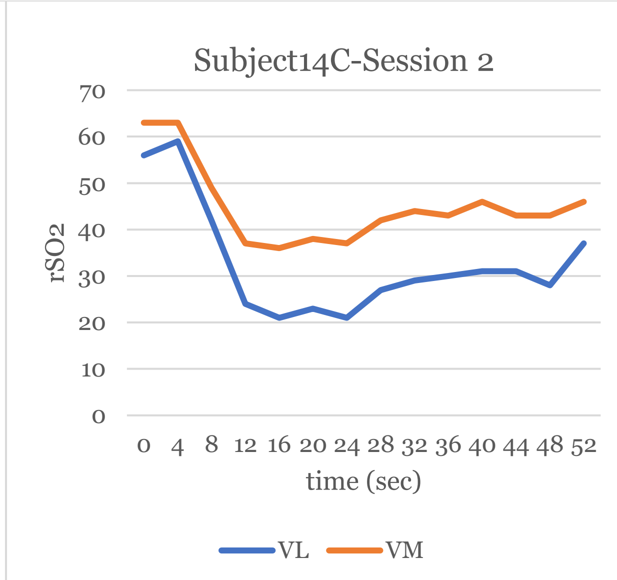
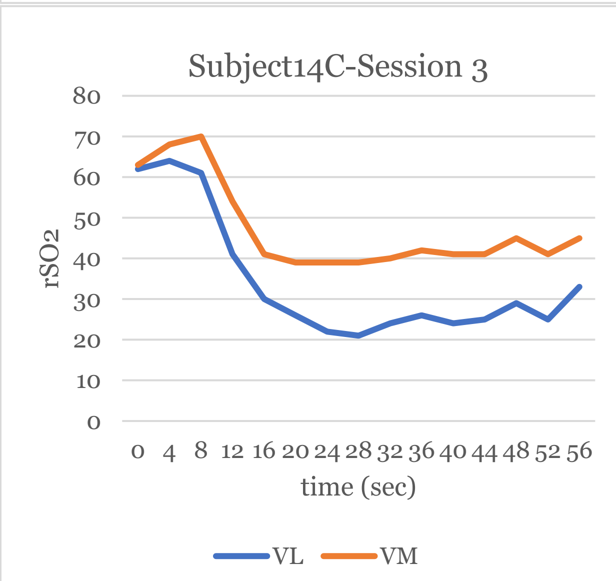
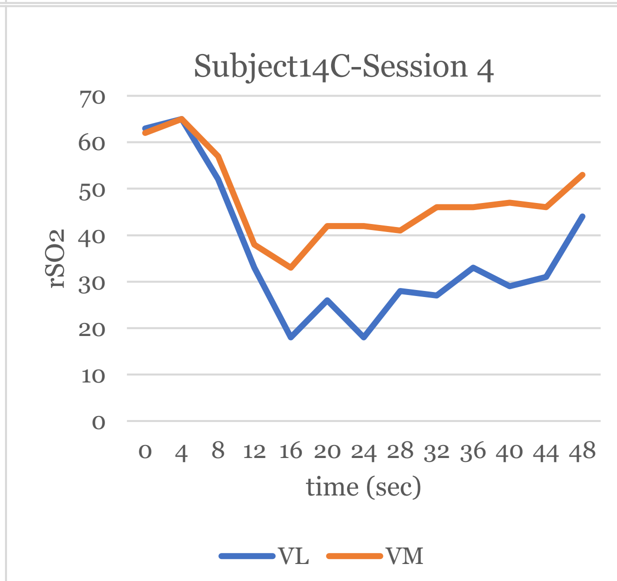


Figure I27: Regional muscle oxygenation saturation in the treatment knee of subject s14 across 7 sessions


Subject14C-Session 1
70
60
50
40
30
20
10
0
rSO2
0 4 8 12 16 20 24 28 32 36 40 44 48 52 56 60
time (sec)
VL
VM


Subject14C-Session 2
70
60
50
40
30
20
10
0
rSO2
0 4 8 12 16 20 24 28 32 36 40 44 48 52
time (sec)
VL
VM


Subject14C-Session 3
80
70
60
50
40
30
20
10
0
rSO2
0 4 8 12 16 20 24 28 32 36 40 44 48 52 56
time (sec)
VL
VM


Subject14C-Session 4
70
60
50
40
30
20
10
0
rSO2
0 4 8 12 16 20 24 28 32 36 40 44 48
time (sec)
VL
VM

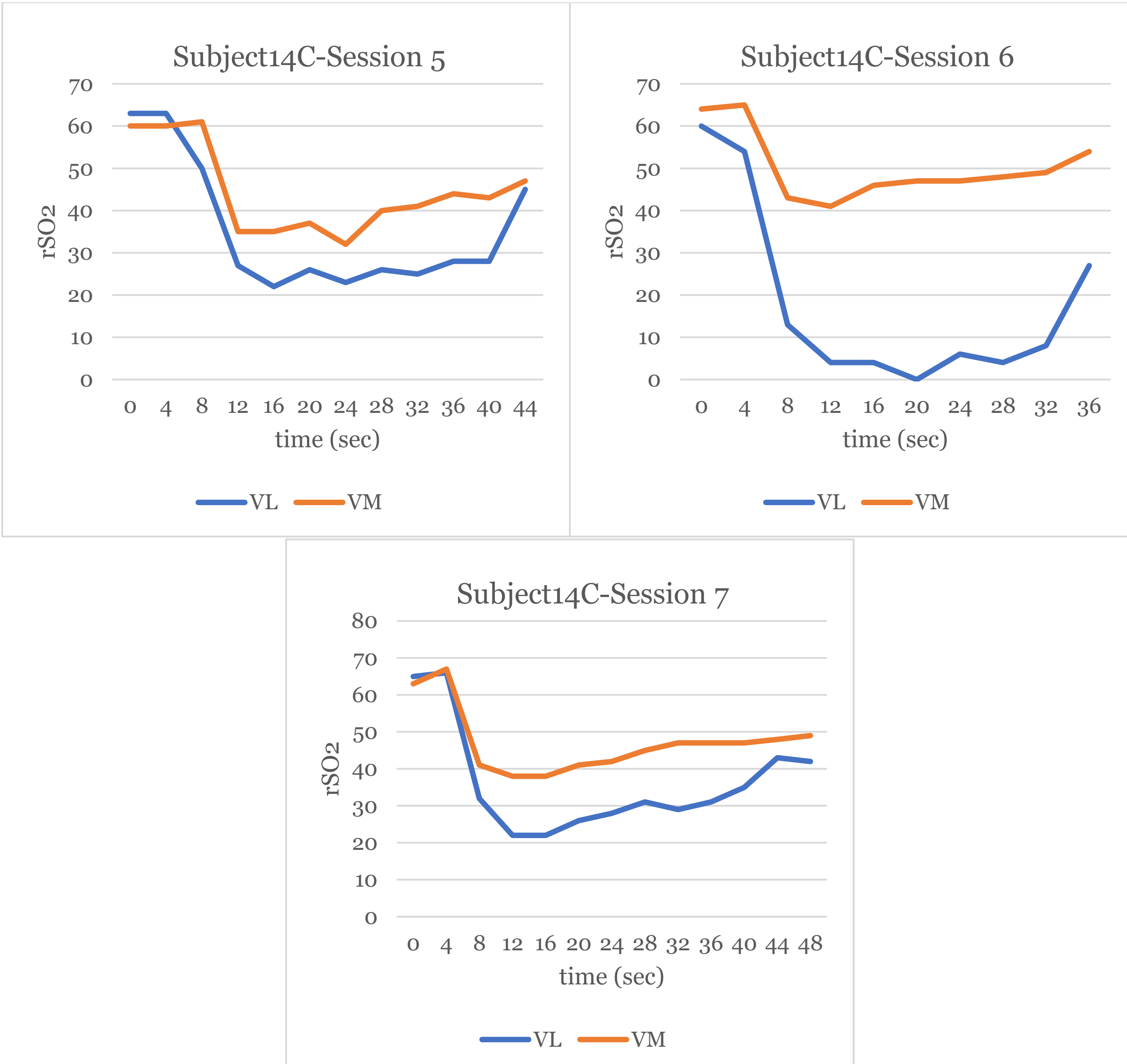


Figure I28: Regional muscle oxygenation saturation in the control knee of subject s14 across 7 sessions

Appendix J: Subject Questionnaire

Structured Interview
Q1. Have you ever worn Kinesio Tape before? Brand? Where?
A1.
Q2. Have you ever had any chronic pain, surgeries, or injuries of the knee? If so, please describe.
A2.
Q3. Have you had any knee injuries in the last 6 months? If so, please describe.
A3.
Q4. Are you right or left leg dominant (What leg you kick a soccer ball with?)
A4.
Q5. Are you or have you suffered from any heart condition?
A5.
Q6. Is there any reason why you should not participate in this study?
A6.

Pre-Test Questionnaire (Session: ___)
Q1. What physical activities have you done in the past 24 hours (running, sports, etc.) If so, please list down duration (in hours) and the intense level (rank 1-10, 10 being the most intense)
A1.
Q2. Do you feel sore? If so, rank 1-10, 10 being the sorest
A2.
Q3: Any bruises or pain?
A3:
Q4: How many hours of sleep did you get last night?
A4:
Post-Test Questionnaire (Session: ___)
Q1: Rank how tired you felt after the test? (1-10)
A1:
Q2: How difficult was the task today? (1-10)
A2:
Q3: Did it feel easier than yesterday?
A3:
Q4: Do you think the tape is helping?
A4: