Repeated Measures Investigation of the Change in Between-Limb Gait Asymmetries for Post-ACLR Subjects in an Asymmetric Walking Rehabilitation Protocol

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Abstract

Over 250,000 anterior cruciate ligament (ACL) injuries occur annually. Despite ACL reconstruction (ACLR) and rehabilitation, between-limb gait differences can persist in Post-ACLR individuals. Gait differences lead to altered limb loading rates which contribute to detrimental knee loading and the initiation of post traumatic knee osteoarthritis. Rehabilitation efforts and return-to-sport criteria are often directed at restoring between-limb symmetry. While this is challenging, stroke research offers a promising approach that utilizes asymmetric walking. Asymmetric walking functions to correct adverse between-limb gait differences and occurs when an individual is made to intentionally walk with each limb moving at a different speed. Repeated measures analysis was used to assess the effect of asymmetric walking in restoring between-limb loading rate symmetry using the loading rate gait changes in the injured and Non-injured limbs. The hypothesis that Post-ACLR individuals adopted symmetric between-limb loading rates in response to the asymmetric walking protocol was supported. An initial higher average loading rate was predicted for the Post-ACLR limb with a decrease over time.

Key Words: Repeated Measures anterior cruciate ligament gait differences return to sport asymmetric walking limb loading rate

1. Introduction

Anterior cruciate ligament (ACL) sprain or tear are common and they are encountered by one in 3,000 individuals annually (Boden et al. 2000). Despite advancements in research and ACL injury prevention programs, ACL injury rates have continued to rise (Donnelly et al. 2012). ACL injury results in the loss of dynamic knee stability which is vital for movements like running and single-leg jump landing (Ardern et al. 2014). Many studies have been conducted to understand the causes of ACL injury. In their research, Morgan et al. (2014) revealed how elevated gastrocnemius forces compensate for decreased hamstring forces during the weight-acceptance phase of single-leg jump landing and highlighted the implications for anterior cruciate ligament injury risk. Most dynamic knee stability data recorded on individuals during running and jump landing studies are in a time series (i.e., a sequence of data points, typically consisting of successive measurements made over a time interval). Quite often discrete measures are used to evaluate this data, but additional information, not unveiled in the time domain, could possibly provide valuable insight into alterations in knee gait patterns in Post-ACL reconstruction (ACLR) individuals. De Fontenay et al. (2014) and Gao et al. (2010) have assessed dynamic gait stability via methods such as Lyapunov exponents. Also, Morgan et al. (2016) used the Nyquist and Bode stability criteria to assess changes in dynamic knee stability in healthy and anterior cruciate ligament reconstructed individuals during walking.

Despite ACL reconstruction and extensive rehabilitation, between-limb gait differences can persist in Post-ACLR individuals. These gait differences lead to altered limb loading rates which contribute to detrimental knee loading and the initiation of post traumatic knee osteoarthritis. Moreover, these changes likely reflect how Post-ACLR individuals adopt compensatory strategies where they tend to either underload or overload. Hence, early rehabilitation efforts and return-to-sport criteria are often directed at restoring between-limb symmetry. While restoring between-limb symmetry is challenging, stroke research offers a promising approach that utilizes asymmetric walking (Reisman et al. 2007).

Asymmetric walking occurs when an individual is made to intentionally walk with each limb moving at a different speed. This walking asymmetry functions to correct adverse between-limb gait differences. Since asymmetric walking has been little explored in Post-ACLR individuals, this study is designed to evaluate the effectiveness of the asymmetric walking protocol in restoring healthy, between-limb loading rate symmetry in this population. Post-ACLR individuals participated in an asymmetric walking protocol and the adaptive loading rate gait changes were assessed in the Post-ACLR and Non-ACLR limbs. Specifically, we hypothesized that the asymmetric walking would result in the adaptation of symmetric loading rate over time in the Post-ACLR individuals, i.e., the difference in the loading rate values for the Post-ACLR and Non-ACLR limbs would approach zero during the 10-minute protocol period.

2. Methods

2.1 Instrumented Gait Data Collection

Fifty-six markers were placed on each participant. Sagittal plane knee kinematics time-domain data were extracted using the fifty-six markers. Using fast Fourier transforms, the time-domain data were converted to a frequency-domain representation yielding a series of sinusoids. Power and phase spectrum were generated. The amplitude, frequency and phase data components of the Post-ACLR injured and Non-ACLR limbs were collected for analysis. The marker trajectories were recorded at 200Hz with a 12-camera motion analysis system (Motion Analysis Corp, Santa Rosa, USA). Force data were collected at 1200 Hz and heel strike and toe off were determined when the vertical ground reaction force (vGRF) was greater or less than 30N.

2.2 Participants and Experimental Program

Eight Post-ACLR individuals (>1 year from return-to-sport clearance) with varying graft types and an average and standard deviation of age, height, and mass of 20.4 ± 0.9 years, 1.76 ± 0.09 m, 73.0 ± 11.1 kg, respectively, participated in the asymmetric walking protocols. Participants walked on an instrumented split-belt treadmill (Bertec Corporation, Columbus, Ohio) with vertical ground reaction force data collected at 1200 Hz and low pass filtered at 35 Hz using a 4th order Butterworth filter. For the experimental program, each participant performed a five-minute warm-up period at a self-selected walking speed to acclimate to the equipment. Each subject was then randomly assigned to complete one of two asymmetric walking treatment protocols. After a five-minute washout time period, the subject then performed the other asymmetric treatment protocol. The design of the experimental program is provided in Figure 1.

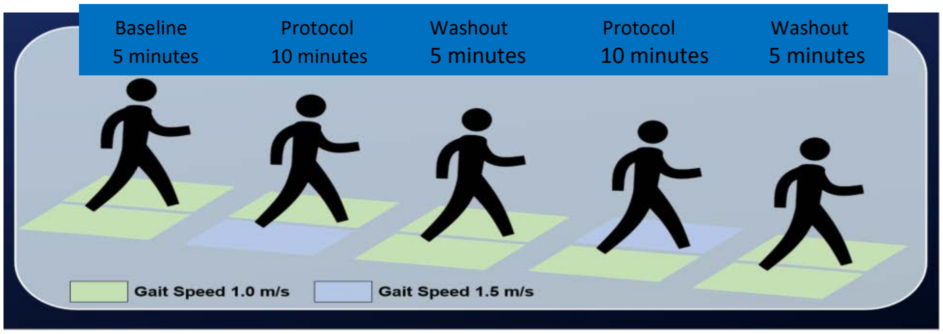


Figure 1: Experimental Program Design for Evaluating Asymmetric Walking Gait Treatment Protocols for Post-ACLR and Non-ACLR Limbs

The two asymmetric walking treatment protocols performed by each subject are described in Table 1. As outlined previously, each subject was given five minutes to walk with both limbs operating at the same self-selected pace to become comfortable with the treadmill equipment. If a subject was randomly assigned to perform Protocol 1 first in the experimental program, the treadmill was set to move at 1.0 m/s under the subject's Post-ACLR limb and at 1.5 m/s under the Non-ACLR limb for ten minutes. After the five-minute washout period, the subject performed Protocol 2 and the treadmill was set to move at 1.5 m/s under the subject's Post-ACLR limb and at 1.0 m/s under the Non-ACLR limb for ten minutes. However, if a subject was randomly assigned to perform Protocol 2 first, the order of performing the treatment protocols for the subject would be reversed. Each subject also performed a five-minute washout at the end of the program. The washout periods allowed the subject to walk at a self-selected speed for both limbs.

Table 1. **Asymmetric Walking Treatment Protocols**

Treatment Protocol 1	Post-ACLR limb moved at 1.0 m/s Non-ACLR limb moved at 1.5 m/s
Treatment Protocol 2	Post-ACLR limb moved at 1.5 m/s Non-ACLR limb moved at 1.0 m/s

2.3 Loading Rate Measurement

Loading rate is an important parameter of gait and it was the main response measurement for the investigation. The loading rate metric captures the speed at which forces are applied to the body and it is critical to monitor and minimize the loading rate to enhance gait symmetry and balance. Decreasing the loading rate applied to tissues will minimize tissue stress. High values of loading rate are often associated with increased risk of injury. The loading rate (body weight/sec) was extracted from the vertical ground reaction force for each limb using a custom MATLAB code (MATLAB R2019a, The MathWorks, Inc., Natick Massachusetts, USA).

For each subject, the average loading rate for each one-minute block of gait walking was computed for each limb. Hence, for each subject, there were ten average loading rate "repeated measures" obtained for each limb - Post-ACLR and Non-ACLR - during each ten-minute protocol segment. This data was used to assess the gait loading rate adaptation pattern over time for each limb for each treatment protocol. The adaptive gait changes were assessed for the Post-ACLR and Non-ACLR limbs. The question to be addressed is whether the participants adopted between-limb loading rate symmetry over time for a given treatment. Table 2 provides the average loading rate for the population of eight participants for the Post-ACLR and Non-ACLR limbs for each minute for each treatment protocol.

Table 2. Average loading rate for Post-ACLR and Non-ACLR Limbs
(mean ± standard deviation)

Treatment Protocol 1: Post-ACLR limb at 1.0 m/s and Non-ACLR limb at 1.5 m/s										
	Minute									
Limb	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
Post-ACLR	*9.2 ±1.6*	*8.5 ±1.6*	*8.1 ±1.5*	*8.1 ±1.8*	*7.9 ±1.8*	*7.8 ±1.8*	*7.6 ±1.7*	*7.7 ±1.6*	*7.6 ±1.5*	*7.5 ±1.4*
Non-ACLR	*7.3 ± 1.4*	*7.1 ±1.5*	*7.2 ±1.5*	*7.4 ±1.4*	*7.3 ±1.4*	*7.4 ±1.5*	*7.2 ±1.5*	*7.4 ±1.4*	*7.4 ±1.4*	*7.6 ±1.5*
Treatment Protocol 2: Post-ACLR limb at 1.5 m/s and Non-ACLR limb at 1.0 m/s										
	Minute									
Limb	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
Post-ACLR	*7.1 ±1.2*	*7.0 ±0.8*	*7.1 ±1.1*	*7.3 ±1.1*	*7.4 ±1.2*	*7.6 ±1.5*	*7.6 ±1.4*	*7.6 ±1.6*	*7.6 ±1.5*	*7.7 ±1.3*
Non-ACLR	*8.2 ±0.9*	*7.7 ±1.1*	*7.4 ±0.9*	*7.4 ±0.9*	*7.3 ±0.8*	*7.2 ±0.9*	*7.1 ±0.9*	*7.1 ±0.8*	*7.3 ±0.9*	*7.1 ±0.9*

For both protocols, at each minute the standard deviation of the loading rate was slightly smaller for the Non-ACLR limb in comparison to the Post-ACLR limb. For Protocol 1, in all but one instance, the loading rate captured at each minute was higher for the Post-ACLR limb. For Protocol 2, the average loading rate captured at each minute was higher for the Non-ACLR limb for minutes one to four. However, the trend was reversed for minutes five to ten.

2.4 Profile Plots Analysis

When several repeated values of a response measurement of interest are captured on each subject, a response profile or curve of values is generated for each subject. A profile plot is a scatterplot showing the loading rate response versus time drawn separately for each limb for each subject. The plots are important in the preliminary analysis of the repeated measures and they are useful for identifying an overall effect and structuring a model. The plots also highlight the subject-to-subject variability in the data and validate to what extent the general pattern is evident in different subjects. Hence, the focus is often centered on identifying if that profile of repeat values for a subject is flat or changes with some pattern. Hence, it is important to look for within-subject effects. Additionally, if the study includes several groups of subjects, there is interest in knowing if the profiles for the different groups are the same (i.e., parallel) or the profiles for the groups tend to cross or intersect each other which indicates there is an interaction effect for the groups. The profile plots of the mean loading rate for the Post-ACLR and Non-ACLR limbs for each of the eight subjects for each treatment protocol are shown in Figure 2.

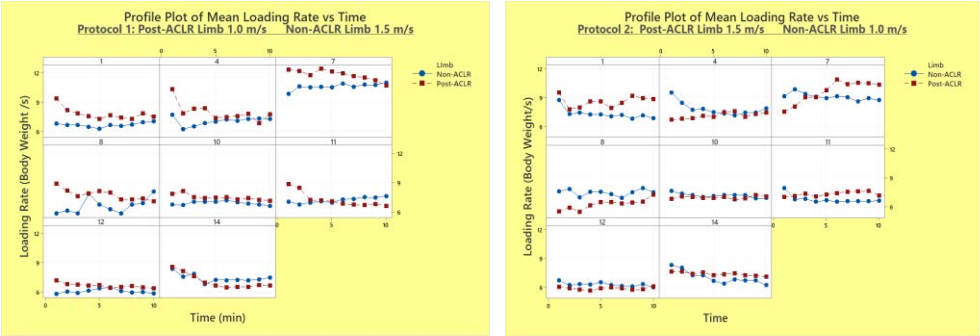


Figure 2: Profile Plots of Mean Loading Rate vs Time for Post-ACLR and Non-ACLR Limbs per subject for Asymmetric Protocols 1 and 2

For Protocol 1, the Post-ACLR limb initially has a higher mean loading rate and over time the difference in the mean loading rate for the Post-ACLR and Non-ACLR limbs approaches zero at minute 10. For Protocol 2, in most cases, the Post-ACLR limb initially has a lower mean loading rate but the differences in the mean loading rate for the two limbs does not always approach zero at minute 10.

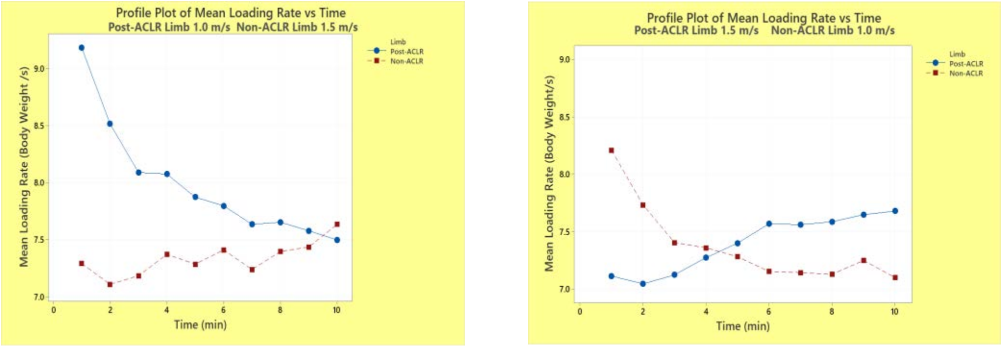


Figure 3: Population Profile Plots of Mean Loading Rate for Post-ACLR and Non-ACLR limbs for Asymmetric Protocols 1 and 2

For the population of eight subjects, Figure 3 gives the profile plots of the mean loading rates for the Post-ACLR and Non-ACLR limbs over time for each of the two asymmetric walking protocols. (This information is also provided in Table 2 above.) All of these plots are critical to both outlining and answering come of the central questions to be addressed in the repeated measures model investigation later, such as:

1. Are the population profiles of the average loading rate for the two limbs similar, in the sense that the line segments for each limb are parallel? *In essence, this question refers to the hypothesis of no loading rate by limb interaction.*
2. If the two population mean profiles are indeed parallel, are they also at the same level? *This question addresses the hypothesis of equal limb effects.*
3. Again, assuming parallelism, are the population means of the loading rate for the two limbs different?

The general trends identified in Figure 2 are also present in Figure 3. Both figures highlight that for both Protocols 1 and 2, the mean profile lines for each limb are not parallel and quite often the two profile lines cross each other which suggests that there is a limb and time interaction effect.

3. Repeated Measures Analysis of Variance Model

3.1 Overview

The repeated measures design is a research or experimental design in which each experimental unit (or subject) is measured at two or more points in time on the same response variable. A repeated measure is a special type of multivariate response which occurs when the same variable is measured on each subject several times, often under different conditions. Quite often in these studies, the question(s) of interest drives the analysis of the data. In some instances, the several responses are reduced to one or two summaries that address the question of interest and the analyses are performed using the summaries as responses. The summaries might consist of the average, the maximum, or the change in the repeated measure. Blocking is often done on the subjects to control for variability between subjects. Hence, each subject then acts as its own control. The term longitudinal data is also used for this type of data. The responses for the same individual are dependent, whereas the scores for different individuals are independent. The repeated measures studies investigate either (1) changes in mean scores over three or more time points, or (2) differences in mean scores under three or more conditions. We are interested in changes in the mean scores per limb over the ten minutes or time points in the protocol.

Quite often diagnosing healthy knee status after ACL reconstruction (ACLR) is based on qualitative observations of the patient's gait, physical examinations of the muscle tone, inspection of gait analysis metrics and the expertise of clinical professionals. Our goal is to develop a mixed effects model to describe the response, an observed mean loading rate measurement. It is a mixed effects model because some model terms are random (subject) and others are fixed (time and limb). This paper examines using a repeated measures Analysis of Variance (ANOVA) model for the k^{th} observation or reading of the mean loading rate on the i^{th} limb for the j^{th} subject

X_{ijk} , the k^{th} reading of the mean loading rate on the i^{th} limb for the j^{th} subject

$$X_{ijk} = \mu + \alpha_i + B_j + G_{ij} + \varepsilon_{ijk}$$

where i = 1, 2 Limb j = 1, 2, 3, …, 8 subjects k = 1, 2, 3, …, 10 minutes

and

> μ *and* $\alpha_i' s$ *are constants with* $\sum \alpha_i 0$, *and the* $B_j' s$, $G_{ij}' s$ *and* $\varepsilon_{ijk}' s$ are independent, normally distributed random variables with unexpected value 0 and variances σ_B^2 , σ_G^2 *and* σ^2, respectively.

- Subject is a "random" factor assumed to have mean o and unknown constant variance. "Random" means the subjects are considered to be a random sample from a larger population of subjects.
- Treatments are different on each limb and the treatment factor measures whether the mean response differs for the two treatments when we average over all subjects and all times.
- Time factor measures whether the mean response differs over time when we average over all subject and all treatments.
- Time*treatment interaction will help to assess whether the pattern across time depends upon the specific treatment used.

The hypotheses to be tested at the 0.05 significance level are

$$H_{OA}: \quad \alpha_1 = \alpha_2 = 0 \qquad versus \qquad H_{aA}: at\ least\ one\ \alpha_i \neq 0$$

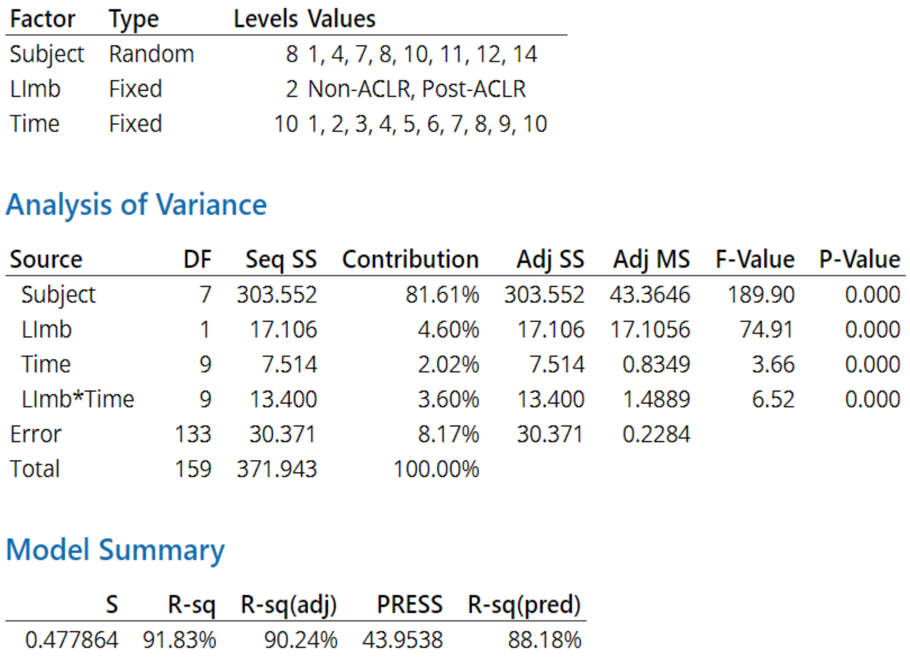
$$H_{OB}: \quad \sigma_B^2 = 0 \qquad versus \qquad H_{aB}: \sigma_B^2 > 0$$

$$H_{OG}: \quad \sigma_G^2 = 0 \qquad versus \qquad H_{aB}: \sigma_G^2 > 0$$

4. Statistical Analysis

4.1 Repeated Measures Statistical Analysis

The Minitab 19.0 software was used to fit a mixed effects repeated measures ANOVA model to the data for both asymmetric Protocol 1 and 2. Both the profile plots and the results from the mixed effects model fit, indicated that Protocol 2 did not perform as well as Protocol 1. Hence, only the findings from Protocol 1 are discussed here. The mixed effect model output is shown in Figure 4.



```
Factor   Type     Levels Values
Subject  Random        8 1, 4, 7, 8, 10, 11, 12, 14
LImb     Fixed         2 Non-ACLR, Post-ACLR
Time     Fixed        10 1, 2, 3, 4, 5, 6, 7, 8, 9, 10

Analysis of Variance

Source       DF   Seq SS  Contribution   Adj SS   Adj MS  F-Value  P-Value
  Subject     7  303.552        81.61%  303.552  43.3646   189.90    0.000
  LImb        1   17.106         4.60%   17.106  17.1056    74.91    0.000
  Time        9    7.514         2.02%    7.514   0.8349     3.66    0.000
  LImb*Time   9   13.400         3.60%   13.400   1.4889     6.52    0.000
Error       133   30.371         8.17%   30.371   0.2284
Total       159  371.943       100.00%

Model Summary

       S    R-sq  R-sq(adj)    PRESS  R-sq(pred)
0.477864  91.83%     90.24%  43.9538      88.18%
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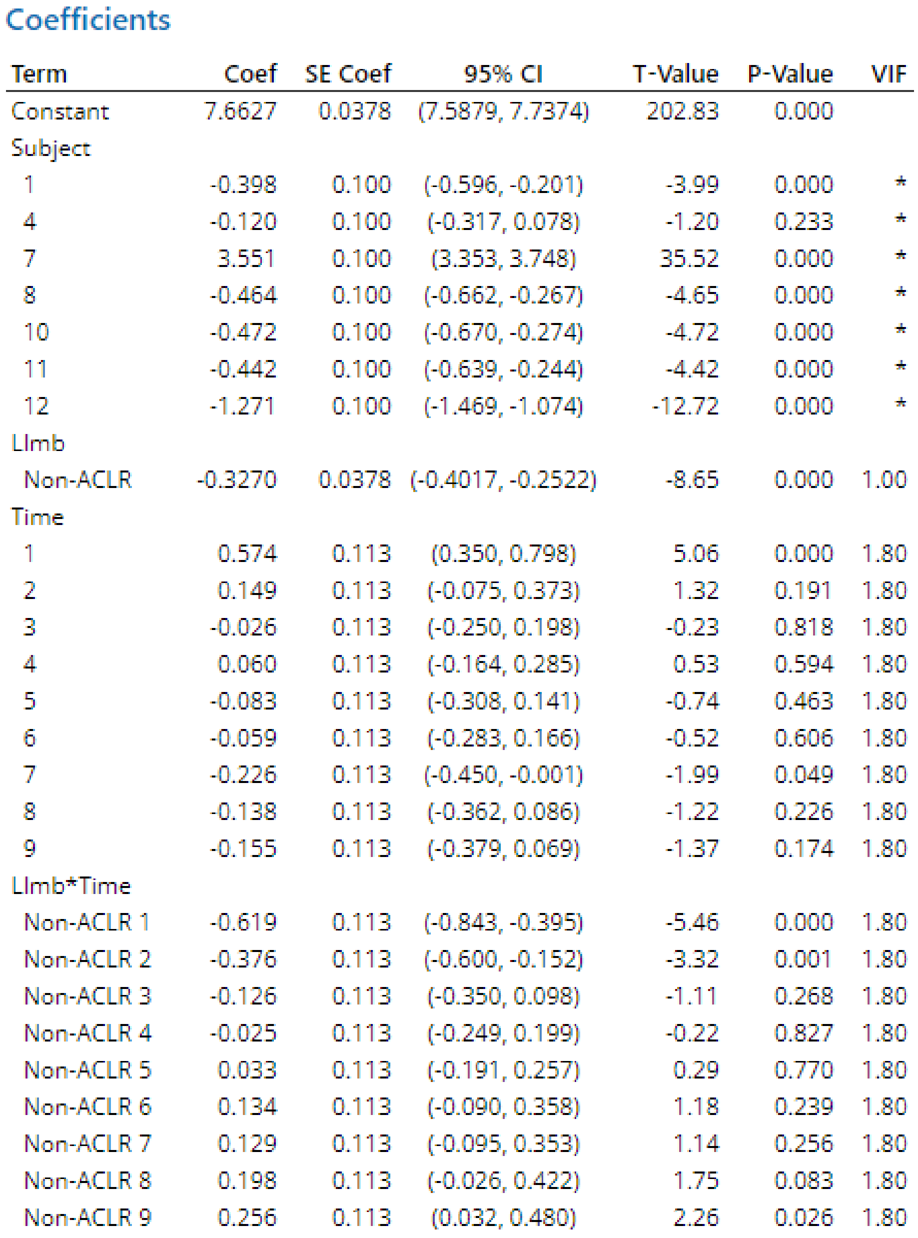


Coefficients

Term	Coef	SE Coef	95% CI	T-Value	P-Value	VIF
Constant	7.6627	0.0378	(7.5879, 7.7374)	202.83	0.000	
Subject						
1	-0.398	0.100	(-0.596, -0.201)	-3.99	0.000	*
4	-0.120	0.100	(-0.317, 0.078)	-1.20	0.233	*
7	3.551	0.100	(3.353, 3.748)	35.52	0.000	*
8	-0.464	0.100	(-0.662, -0.267)	-4.65	0.000	*
10	-0.472	0.100	(-0.670, -0.274)	-4.72	0.000	*
11	-0.442	0.100	(-0.639, -0.244)	-4.42	0.000	*
12	-1.271	0.100	(-1.469, -1.074)	-12.72	0.000	*
LImb						
Non-ACLR	-0.3270	0.0378	(-0.4017, -0.2522)	-8.65	0.000	1.00
Time						
1	0.574	0.113	(0.350, 0.798)	5.06	0.000	1.80
2	0.149	0.113	(-0.075, 0.373)	1.32	0.191	1.80
3	-0.026	0.113	(-0.250, 0.198)	-0.23	0.818	1.80
4	0.060	0.113	(-0.164, 0.285)	0.53	0.594	1.80
5	-0.083	0.113	(-0.308, 0.141)	-0.74	0.463	1.80
6	-0.059	0.113	(-0.283, 0.166)	-0.52	0.606	1.80
7	-0.226	0.113	(-0.450, -0.001)	-1.99	0.049	1.80
8	-0.138	0.113	(-0.362, 0.086)	-1.22	0.226	1.80
9	-0.155	0.113	(-0.379, 0.069)	-1.37	0.174	1.80
LImb*Time						
Non-ACLR 1	-0.619	0.113	(-0.843, -0.395)	-5.46	0.000	1.80
Non-ACLR 2	-0.376	0.113	(-0.600, -0.152)	-3.32	0.001	1.80
Non-ACLR 3	-0.126	0.113	(-0.350, 0.098)	-1.11	0.268	1.80
Non-ACLR 4	-0.025	0.113	(-0.249, 0.199)	-0.22	0.827	1.80
Non-ACLR 5	0.033	0.113	(-0.191, 0.257)	0.29	0.770	1.80
Non-ACLR 6	0.134	0.113	(-0.090, 0.358)	1.18	0.239	1.80
Non-ACLR 7	0.129	0.113	(-0.095, 0.353)	1.14	0.256	1.80
Non-ACLR 8	0.198	0.113	(-0.026, 0.422)	1.75	0.083	1.80
Non-ACLR 9	0.256	0.113	(0.032, 0.480)	2.26	0.026	1.80

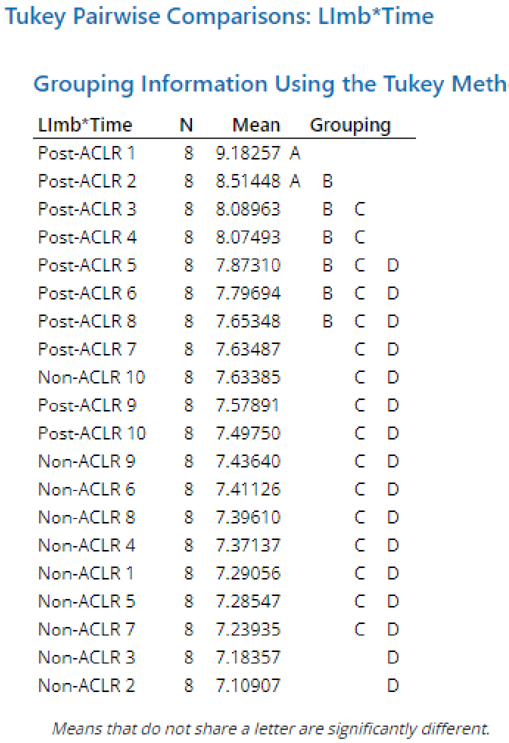
Figure 4: Repeated Measures ANOVA Mixed Effects Model Analysis Output for Post-ACLR and Non-ACLR limbs for Asymmetric Protocol 1

For Protocol 1, the repeated measures ANOVA mixed effect model performed very well with an adjusted $R^2 = 0.90$. At the 0.05 statistical significance level, there is a significant time and limb interaction effect ($p<0.0001$) which indicates that the pattern of change in the average loading rate differs for the two limb treatments – Post-ACLR and Non-ACLR - over time. This was also revealed in the profile plots which showed that the limb patterns were not parallel for the two limbs for the subjects. Also, the model results show that there is a significant time ($p<0.0001$) and limb effect ($p<0.001$). From the profile plots it appears that the average loading rates for the Post-ACLR limb tend to decline from the start to the end of the ten minute protocol period while the average loading rate for the Non-ACLR limb tends to increase. In both cases, the average loading rate changes over time and are not constant or equal for the Post-ACLR and Non-ACLR limbs. The profile plots illustrate that, at minute 10, the average loading rates for the two limbs are approximately the same.

4.2 Tukey Post-Hoc Comparison of Means Analysis

The multiple comparisons of means will yield key insight to examine which means are different and to estimate how much they are different. Note, Table 3 gives the Tukey Pairwise Comparisons and grouping information for the mean loading rates for the two limbs at each minute in Protocol 1 and Table 4 gives the simultaneous 95% confidence interval on the difference in the mean loading rate for the two limbs for selected minutes. The means for the Post-ACLR and Non-ACLR limbs at minutes 9 and 10 are not significantly different. Hence, the mean loading rates for the two limb treatments are approximately equal at the end of the protocol and there are more changes in the mean loading rates for the Post-ACLR limb over the ten-minute period. Also, the simultaneous 95% confidence interval on the difference in Post-ACLR and Non-ACLR mean loading rates includes zero at minute 10 and this is not the case at the start of the protocol at minute 1.

Table 3: Tukey Pairwise Comparisons – Limb*Time of Mean Loading Rate for Asymmetric Protocol 1



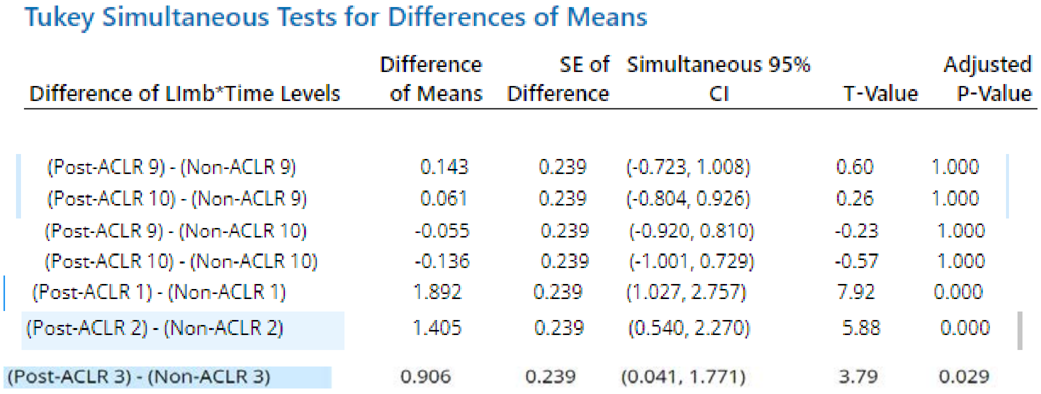
Tukey Pairwise Comparisons: LImb*Time

Grouping Information Using the Tukey Method and 95% Confidence

LImb*Time	N	Mean	Grouping			
Post-ACLR 1	8	9.18257	A			
Post-ACLR 2	8	8.51448	A	B		
Post-ACLR 3	8	8.08963		B	C	
Post-ACLR 4	8	8.07493		B	C	
Post-ACLR 5	8	7.87310		B	C	D
Post-ACLR 6	8	7.79694		B	C	D
Post-ACLR 8	8	7.65348		B	C	D
Post-ACLR 7	8	7.63487			C	D
Non-ACLR 10	8	7.63385			C	D
Post-ACLR 9	8	7.57891			C	D
Post-ACLR 10	8	7.49750			C	D
Non-ACLR 9	8	7.43640			C	D
Non-ACLR 6	8	7.41126			C	D
Non-ACLR 8	8	7.39610			C	D
Non-ACLR 4	8	7.37137			C	D
Non-ACLR 1	8	7.29056			C	D
Non-ACLR 5	8	7.28547			C	D
Non-ACLR 7	8	7.23935			C	D
Non-ACLR 3	8	7.18357				D
Non-ACLR 2	8	7.10907				D

Means that do not share a letter are significantly different.

Table 4: Tukey Simultaneous Tests for Differences of Mean Loading Rate – Limb*Time for Selected Minutes in the Asymmetric Protocol 1



Tukey Simultaneous Tests for Differences of Means

Difference of LImb*Time Levels	Difference of Means	SE of Difference	Simultaneous 95% CI	T-Value	Adjusted P-Value
(Post-ACLR 9) - (Non-ACLR 9)	0.143	0.239	(-0.723, 1.008)	0.60	1.000
(Post-ACLR 10) - (Non-ACLR 9)	0.061	0.239	(-0.804, 0.926)	0.26	1.000
(Post-ACLR 9) - (Non-ACLR 10)	-0.055	0.239	(-0.920, 0.810)	-0.23	1.000
(Post-ACLR 10) - (Non-ACLR 10)	-0.136	0.239	(-1.001, 0.729)	-0.57	1.000
(Post-ACLR 1) - (Non-ACLR 1)	1.892	0.239	(1.027, 2.757)	7.92	0.000
(Post-ACLR 2) - (Non-ACLR 2)	1.405	0.239	(0.540, 2.270)	5.88	0.000
(Post-ACLR 3) - (Non-ACLR 3)	0.906	0.239	(0.041, 1.771)	3.79	0.029

4.3 Model Validation and Assessment Analysis

Plots are beneficial for verifying the plausibility of the normality and constant variance assumptions for the mixed effects model. The normal probability plot of the residuals in Figure 5 is sufficiently straight and hence there is no concern about the normality assumption. Likewise, in Figure 6, the plot of the residuals against the predicted values has a fairly uniform vertical spread, so there is no concern about the constant variance assumption.

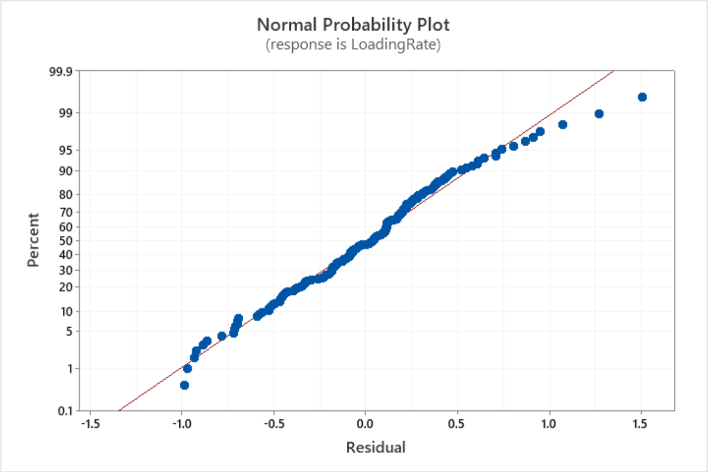


Figure 5: Normal Probability Plot of Residuals

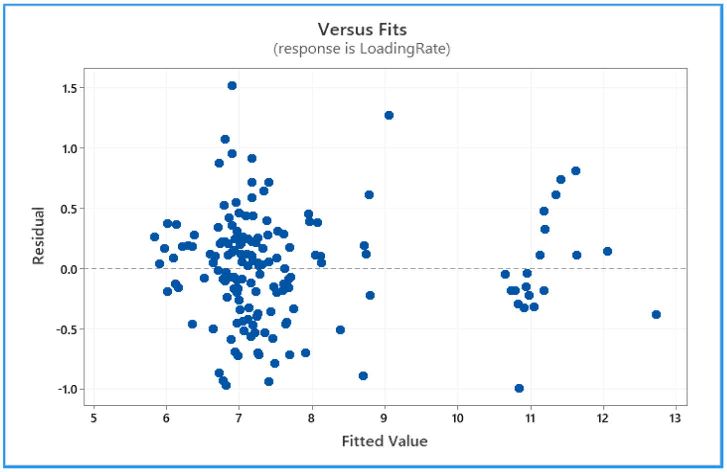


Figure 6: Plot of Residuals versus Model Predicted Values

5. Discussion of Results

5.1 Discussion

The objective of this work was to determine if the asymmetric walking protocols were successful in helping individuals who had anterior cruciate ligament reconstruction adopt a healthy, symmetric loading rate. Using the repeated measures ANOVA, it was possible to conduct an analysis of the mean loading rate response metric on the Non-ACLR and Post-ACLR limb for eight subjects. Here, the asymmetric walking Protocol 1 was able to correct between-limb differences. Moreover, this work revealed that the positive response to the asymmetric walking protocol was dependent on which limb is set at the faster speed. This work demonstrates that the asymmetric walking could result in the adaptation of symmetric loading rate over time in the Post-ACLR individuals, i.e., the difference in the loading rate values for the Post-ACLR and Non-ACLR limbs would approach zero during the 10-minute protocol period.While this study was successful in identifying the adoption of healthy gait dynamics in Post-ACLR individuals in response to the 10-minute asymmetric walking Protocol 1, future work will evaluate the long-term storage of the healthy gait dynamics once the asymmetric gait perturbation is removed and investigate further the asymmetric Protocol 2. Given the large number of Post-ACLR individuals with recurring knee issues, it is important to identify new and more advanced tools and methods for quantifying, monitoring, and classifying healthy knee function.

Acknowledgements

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