FATIGUE AND ACL INJURY RISK

Mason Chen
Stanford Online High School
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Project Motivation

- In the 2019 NBA Finals, Kevin Durant ruptured his Achilles while Klay Thompson suffered an ACL injury
- Thompson won 30 points in the match and helped the Golden State Warriors lead 85-80 before the injury
- Warriors would go on to lose the match 110-114 and the 2019 NBA Finals, missing a chance of an elusive “three-peat”
- Thompson was playing his 6th championship match in just 2 weeks, and his knee was ruptured in the 3rd quarter
- **Was fatigue one of the major factors that caused his injury?**

Project Overview

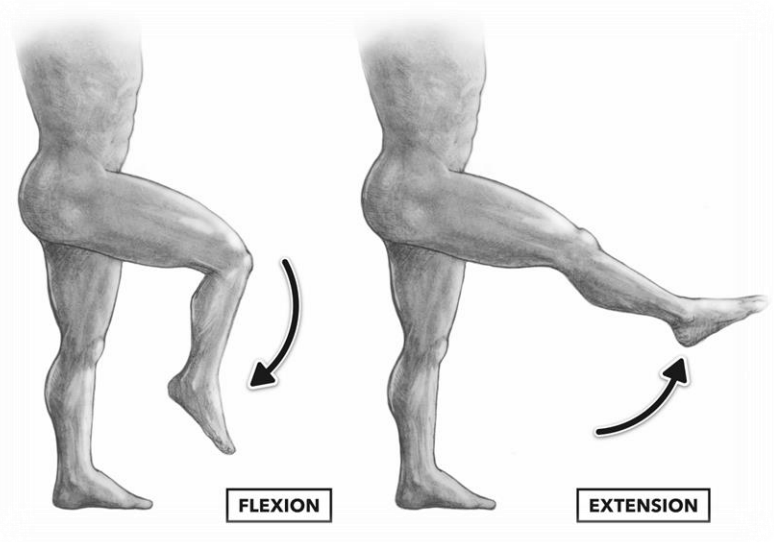
- **Problem Statements**
  - ACL tearing is one of the most common and dangerous injuries in basketball history
  - Recovering from ACL injuries is a brutal and lengthy process (takes months to recover)
  - The injury can significantly decrease player's performance after recovery
- **Project Objectives**
  - Understand how ACL's can be torn and what increases injury risk
  - Design an experiment that can quantify ACL injury risk before and after fatigue
  - Find the relationship between fatigue and angle/force measurements
  - Apply JMP tools such as Multivariate Correlation, Clustering, and Control Charts

ACL Injury

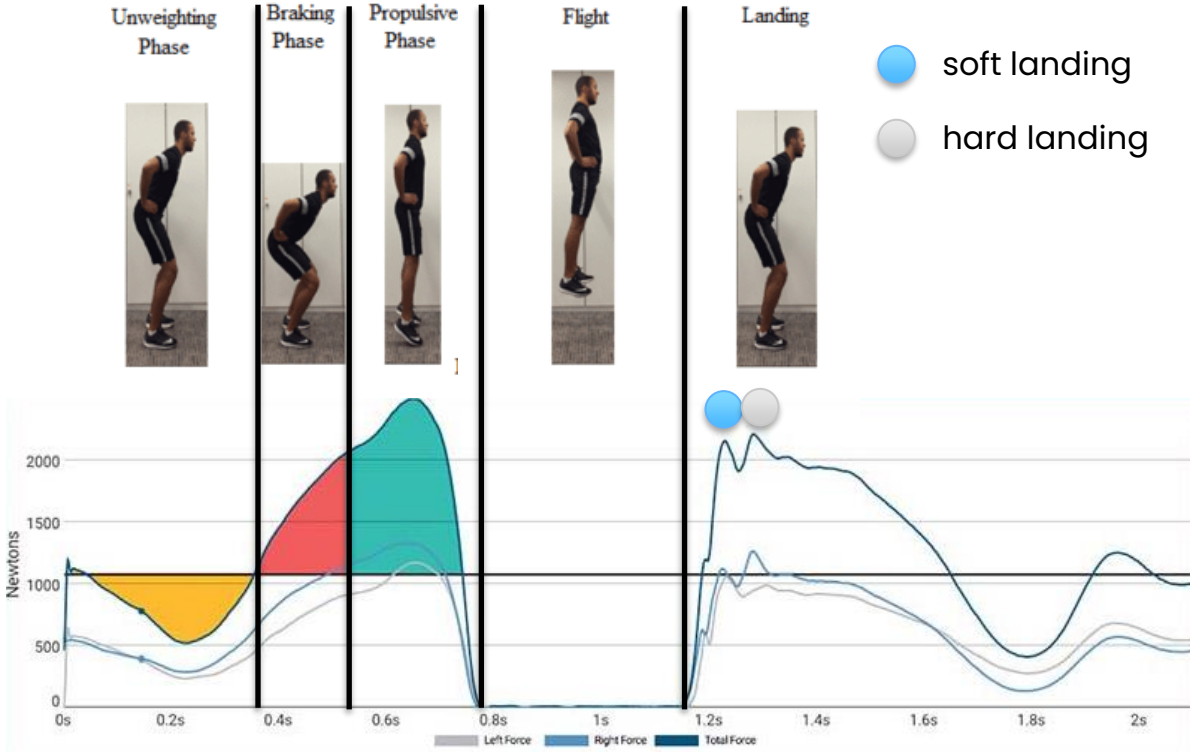
- **If tibia (shinbone) is moved too far forward or hyperextended, ACL can be torn**
  - Sudden deceleration or pivoting in place
  - Foot is planted and body changes direction rapidly
  - Common sports that are source of ACL tears:
    - **Basketball – jumping, landing, and pivoting**
    - Football – planting foot and rapidly changing direction, body contact
    - Downhill skiing – ski boots higher than calf, moving impact of a fall to knee rather than lower ankle or leg

Factors Related to ACL Injury

- Strength and ability to “tighten” quadricep (front of thigh) muscle
- Response of hamstring muscles (back of thigh)
- Knee flexion and vertical forces (Newton’s Third Law)

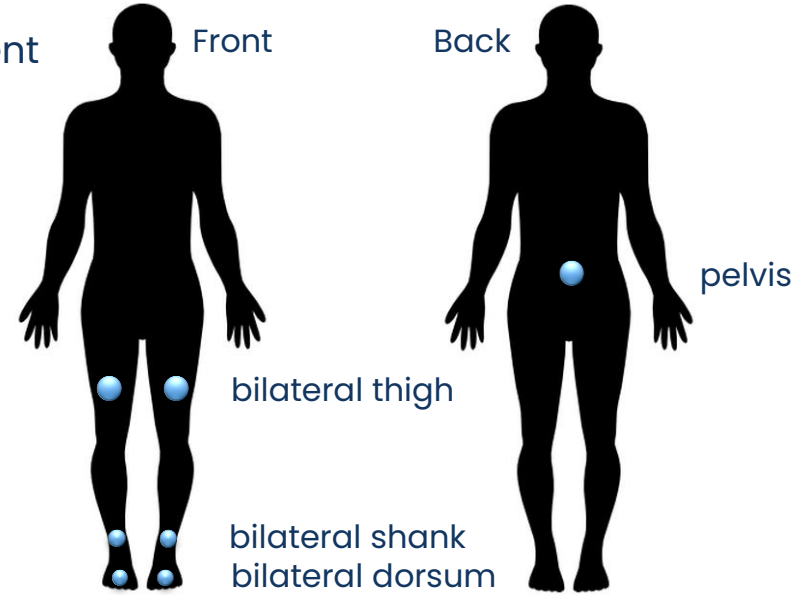


Countermovement Jump



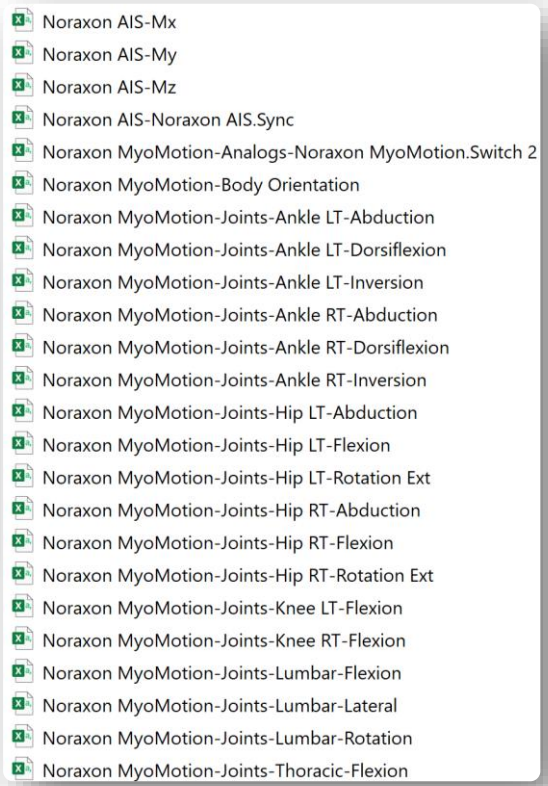
Experimental Design

- 7 different sensors were attached to a test subject while he conducted countermovement jump exercise on force plate (before fatigue)
- 1 hour fatigue period – running, squatting, basketball, jumping, cone drills, etc.
- After fatigue, conducted countermovement jump again to study fatigue factor
- Sensor data was transformed through a biomechanical model to simulate the 3D-motion profiles



Data Collection

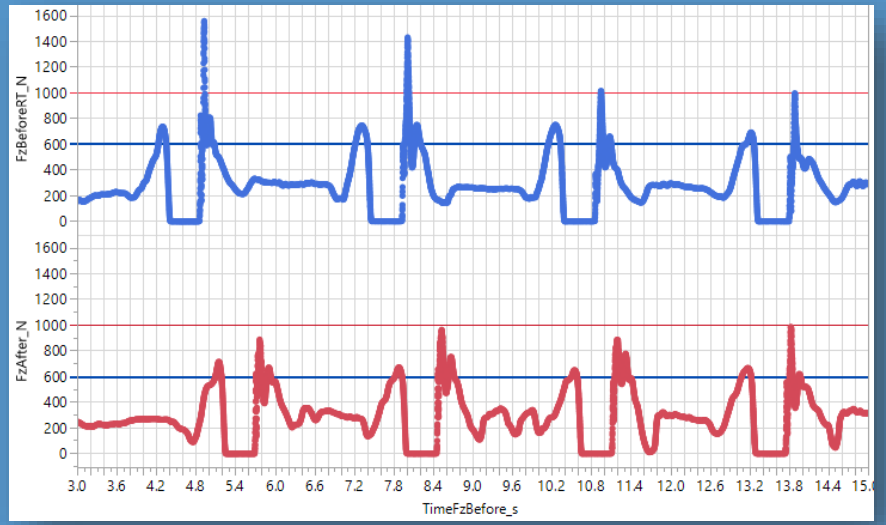
time	x	y	z
-1.105	0.548497	0.446264	0.446264
-1.095	0.547139	0.447927	0.447927
-1.085	0.545717	0.449659	0.449659
-1.075	0.544236	0.45145	0.45145
-1.065	0.54273	0.453259	0.453259
-1.055	0.541223	0.455058	0.455058
-1.045	0.539733	0.456825	0.456825
-1.035	0.539467	0.457138	0.457138
-1.025	0.539117	0.457551	0.457551
-1.015	0.538724	0.458014	0.458014
-1.005	0.538275	0.458541	0.458541



Force Profile

- Fz (vertical force) vs Time (seconds)
- Most soft landing peaks are higher for before than after fatigue
- Force profile indicates a different behavior between before and after fatigue for force

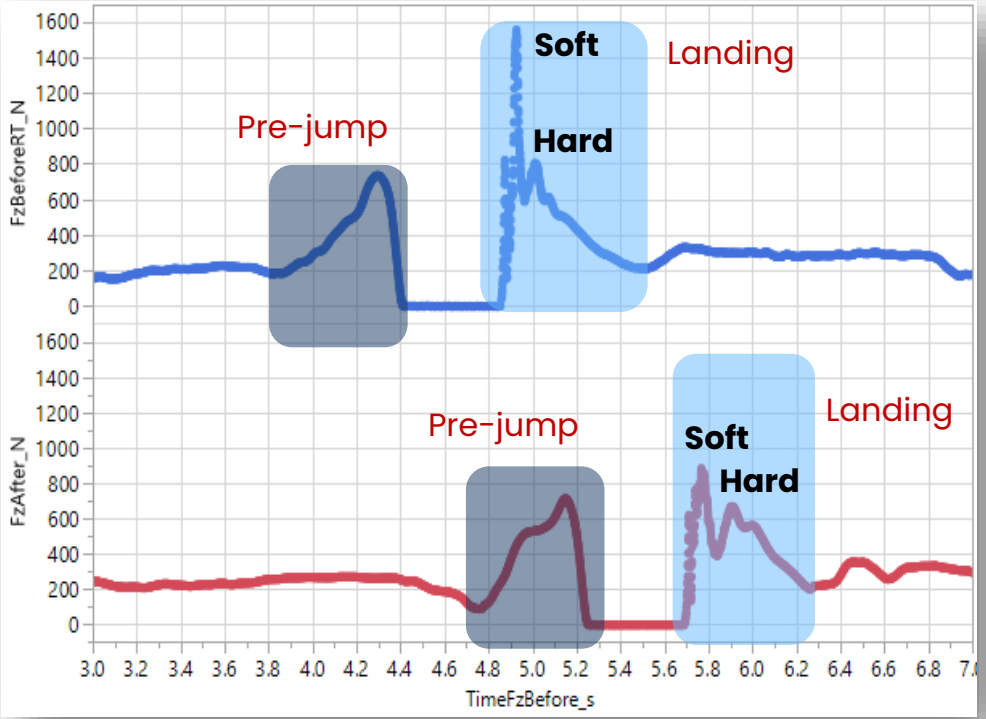
Analyze → Quality and Process →
Control Chart Builder (Individual)



Individual Force Profile

Analyze → Quality and Process →
Control Chart Builder (Individual)

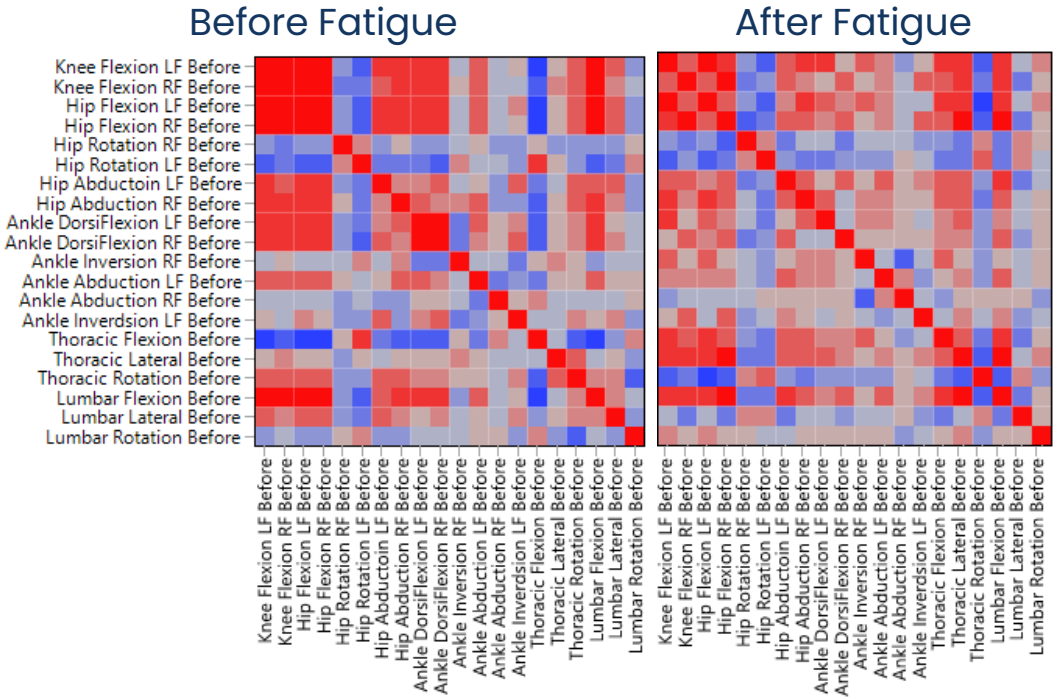
- Pre-jump curve (transition from braking to propulsive phase) is smoother for before fatigue
- May indicate that different body parts are well coordinated (and no plateau)
- 2-step (soft and hard) landing mechanism has greater contrast during before fatigue



Multivariate Correlation

Analyze → Multivariate Methods → Multivariate

- 20 joint angles were collected from the 7 sensors
- Correlation variables are slightly different between before and after fatigue
- **Much more effective to look at a few key parameters that could represent the fatigue factor**



Cluster Variables

Analyze → Clustering → Cluster Variables

- Used to group the parameters in order to identify the most important ones
- Before fatigue, most variance was explained by 1st cluster
- After fatigue, top 2 clusters contributed to most variance

Cluster Summary

Cluster	Number of Members	Most Representative Variable	Cluster Proportion of Variation Explained	Total Proportion of Variation Explained
1	10	Hip Flexion LF Before	0.755	0.378
3	4	Lumbar Rotation Before	0.525	0.105
4	2	Ankle Abduction LF Before	0.786	0.079
2	2	Ankle Inversion RF Before	0.764	0.076
5	2	Ankle Abduction RF Before	0.511	0.051

Proportion of variation explained by clustering: 0.689

Cluster Members

Cluster	Members	RSquare with Own Cluster	RSquare with Next Closest	1-RSquare Ratio
1	Hip Flexion LF Before	0.955	0.34	0.068
1	Knee Flexion LF Before	0.938	0.435	0.11
1	Hip Flexion RF Before	0.933	0.4	0.111
1	Lumbar Flexion Before	0.862	0.49	0.27
1	Thoracic Flexion Before	0.82	0.422	0.312
1	Knee Flexion RF Before	0.825	0.454	0.321
1	Hip Rotation LF Before	0.637	0.235	0.475
1	Hip Abduction RF Before	0.544	0.287	0.639
1	Hip Abductoin LF Before	0.467	0.239	0.7
1	Ankle DorsiFlexion RF Before	0.571	0.512	0.878
2	Ankle Inversion RF Before	0.764	0.094	0.26
2	Ankle Inverdsion LF Before	0.764	0.123	0.269
3	Lumbar Rotation Before	0.736	0.079	0.287
3	Thoracic Rotation Before	0.759	0.297	0.342
3	Lumbar Lateral Before	0.414	0.197	0.73
3	Hip Rotation RF Before	0.189	0.113	0.914

Before Fatigue

Cluster Summary

Cluster	Number of Members	Most Representative Variable	Cluster Proportion of Variation Explained	Total Proportion of Variation Explained
1	7	Hip Flexion LF After	0.668	0.234
2	7	Hip Flexion RF After	0.657	0.23
3	2	Ankle Abduction RF After	0.838	0.084
5	2	Ankle Inversion LF After	0.684	0.068
4	2	Lumbar Rotation After	0.584	0.058

Proportion of variation explained by clustering: 0.674

Cluster Members

Cluster	Members	RSquare with Own Cluster	RSquare with Next Closest	1-RSquare Ratio
1	Hip Flexion LF After	0.903	0.392	0.159
1	Knee Flexion LF After	0.847	0.379	0.247
1	Hip Abduction RF After	0.631	0.226	0.477
1	Hip Rotation LF After	0.627	0.251	0.498
1	Ankle DorsiFlexion LF After	0.464	0.08	0.583
1	Thoracic Rotation After	0.665	0.461	0.622
1	Thoracic Flexion After	0.539	0.317	0.675
2	Hip Flexion RF After	0.871	0.433	0.227
2	Knee Flexion RF After	0.818	0.362	0.285
2	Lumbar Flexion After	0.836	0.515	0.338
2	Hip Rotation RF After	0.488	0.147	0.6
2	Hip Abduction LF AFter	0.515	0.214	0.617
2	Ankle DorsiFlexion RF After	0.374	0.061	0.667
2	Thoracic Lateral After	0.693	0.587	0.743
3	Ankle Abduction RF After	0.838	0.019	0.165
3	Ankle Inversion RF After	0.838	0.204	0.204

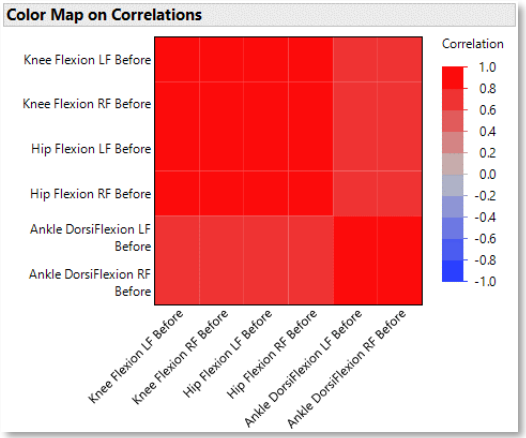
After Fatigue

Flexion Multivariate Correlation

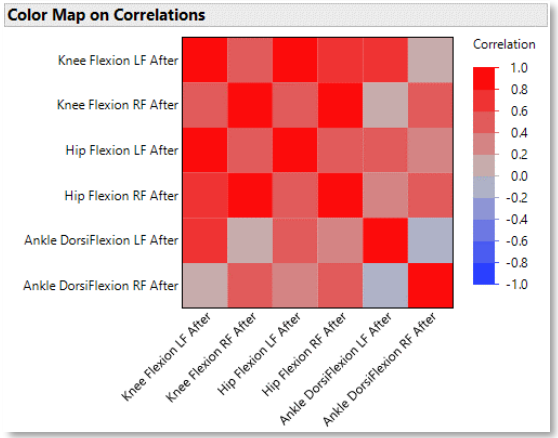
- Multivariate Correlation differences for the 6 key parameters (ankle, knee, hip) is much more obvious than comparing all 20 joint variables
- All 6 variables are very well correlated before fatigue
- Ankle flexion correlation patterns have changed drastically after fatigue

Analyze → Multivariate Methods → Multivariate

Before Fatigue

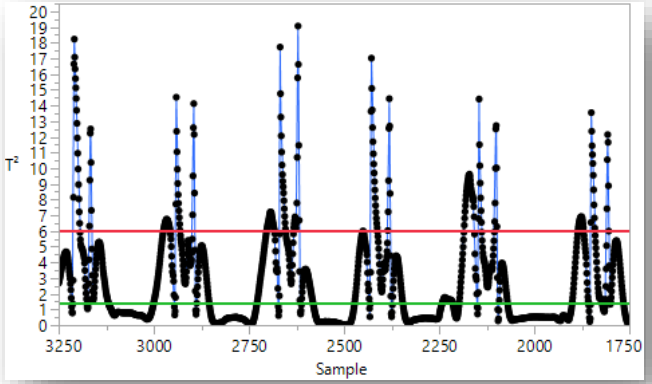


After Fatigue

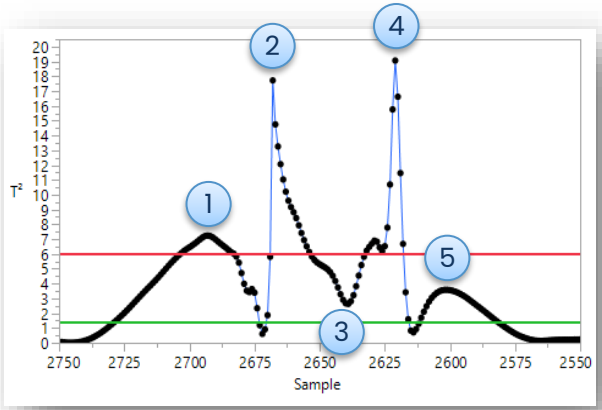


Multivariate Control Chart

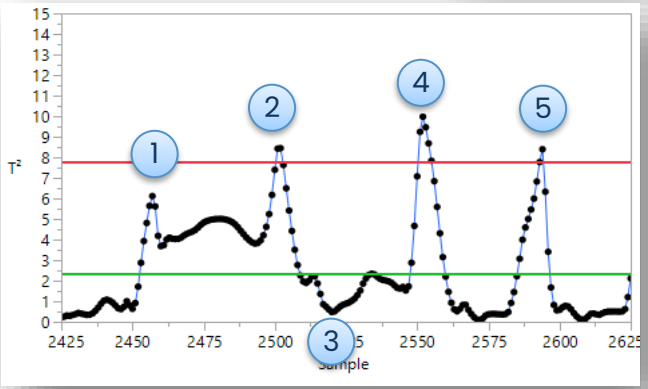
- Multivariate Statistical Process Control Chart studies time domain difference
- More points outside Upper Control Limit for before then after fatigue



Before Fatigue



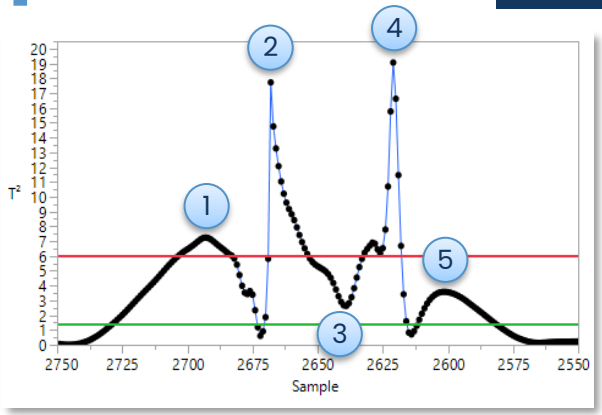
After Fatigue

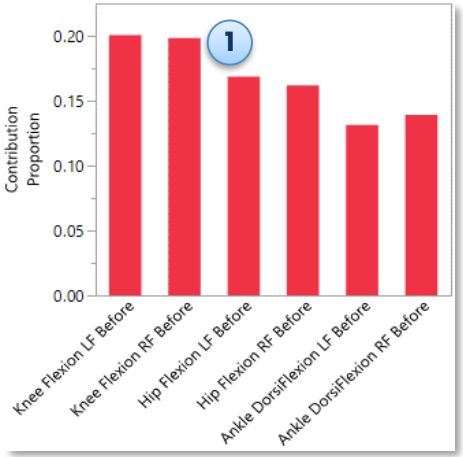


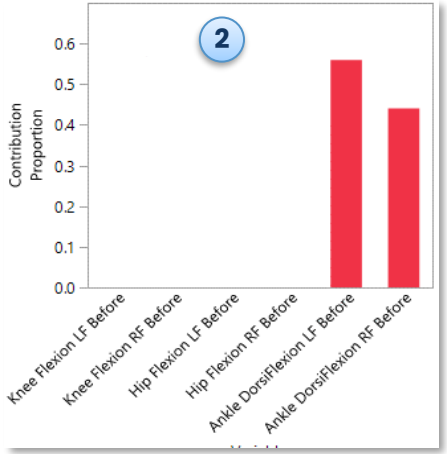
Analyze → Quality and Process → Model Driven Multivariate Control Chart

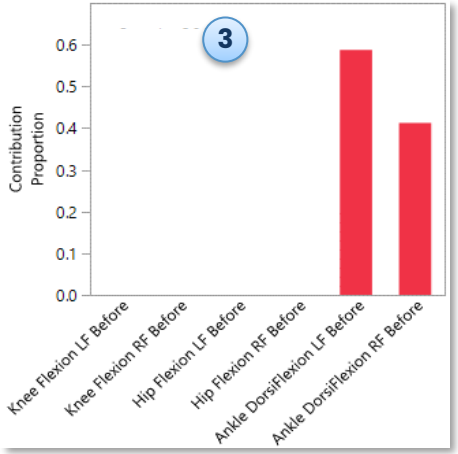
Before Fatigue Contribution

- Flexion contribution patterns were studied at each of the 5 points for before fatigue
- At 1, ankle, knee, and hip are all flexed during bending
- At 2 (right before jumping off the ground) and 3 (in the air), ankle is the dominant component





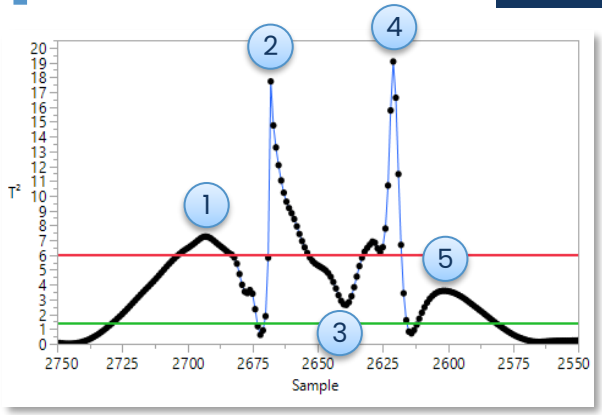


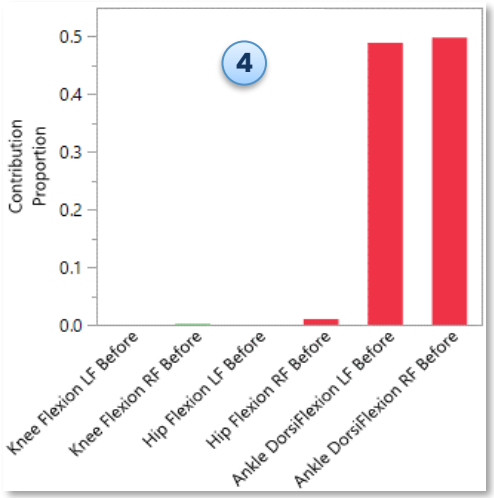


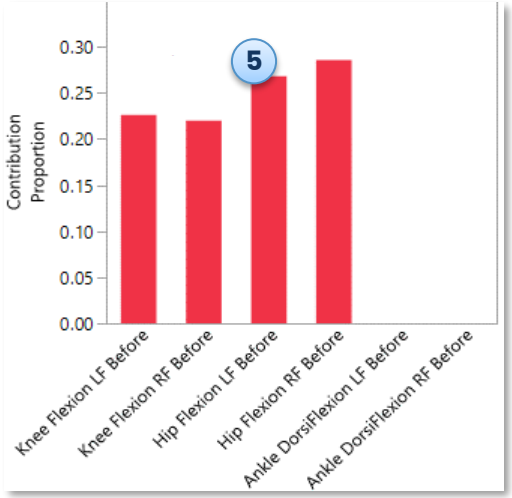
Analyze → Quality and Process → Model Driven Multivariate Control Chart

Before Fatigue Contribution

- At 4, during the soft landing, ankle flexion continues to be the dominant component
- At 5, during the hard landing, hip and knee flexion take over to distribute the forces evenly





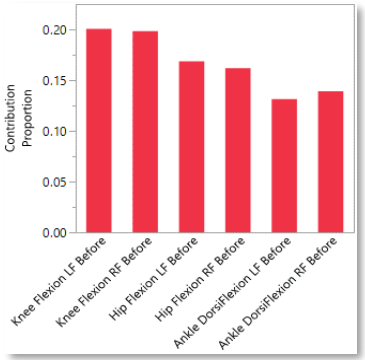


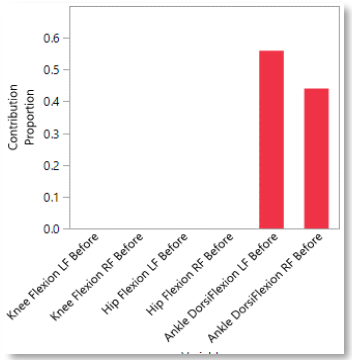
Analyze → Quality and Process → Model Driven Multivariate Control Chart

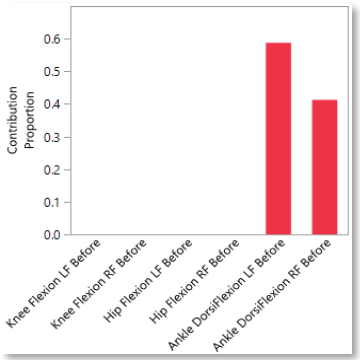
Contribution Comparison

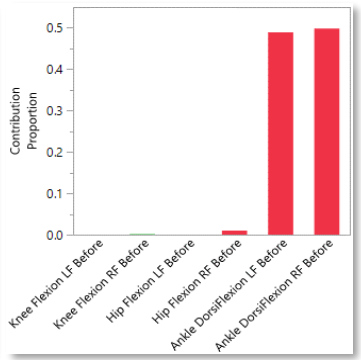
Analyze → Quality and
Process → Model Driven
Multivariate Control Chart

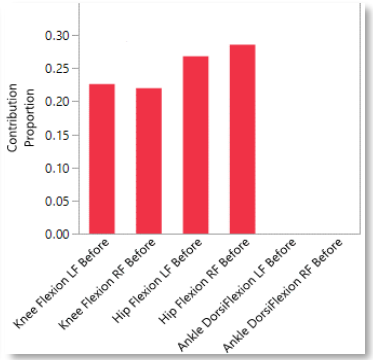
1 2 3 4 5

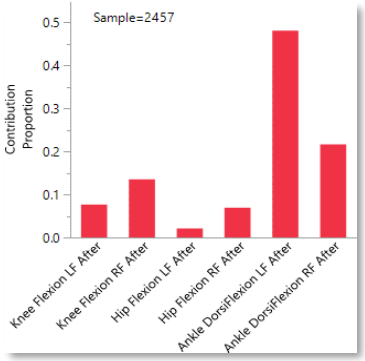


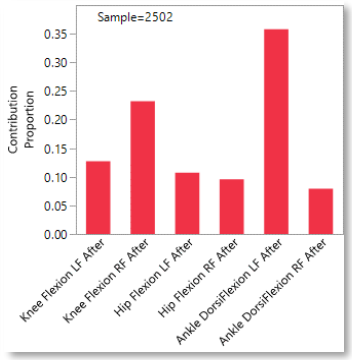


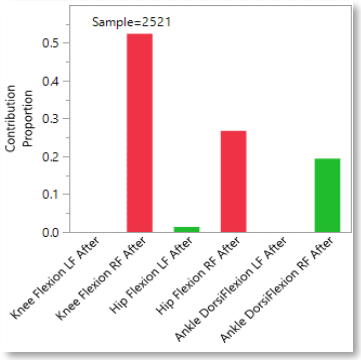


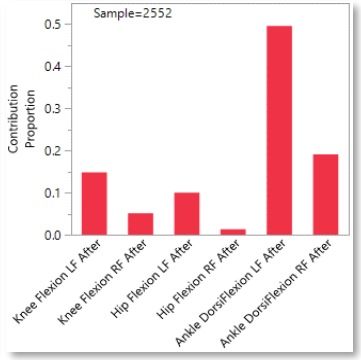


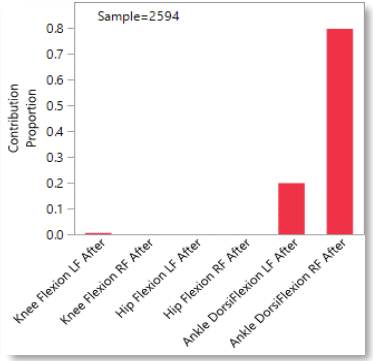












Conclusions

- Studied ACL injury causes and techniques to prevent ACL injury
- Utilized 3D-motion sensors and the countermovement jump to design an experiment that can effectively measure and compare ACL injury risk
- Used Variable Clustering and scientific reasoning to find the key parameters to analyze (ankle, knee, and hip joint angles)
- Multivariate Correlation compared before and after fatigue pattern
- Multivariate Control Chart found specific points where the joint flexion differed most while Contribution Proportion helped understand the effects of fatigue

Future research – study 90 degree cut and lateral shuffle exercises which measure different positions of ACL injury risk and is highly used in basketball defense