Analyzing ACL Injury Risk Using 3D-Motion Sensors and Various Statistical Methods

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Abstract

This paper will focus on studying the biomechanics related to the ACL injury through 3D-motion sensors. A specially designed countermovement force test was conducted before and after a 2-hour exercise window to fatigue the muscles associated with the ACL injury. 7 sensors were placed on the body to derive the 3D-motion biomechanics. The fatigue factor associated with ACL injury risk was particularly addressed through the contact forces and the joint flexion profiles during both the jumping and landing periods. When the body muscles are fatigued, the knee cannot be held as steadily and provide enough knee cushion during the soft toes' landing period. This period is crucial to protecting the ACL in the hard landing that immediately follows. The Multivariate Correlation was implemented to choose the most important variables that reflected ACL injury risk from the 20 total joint angles collected. Modern Principle Component Analysis (PCA) based Multivariate SPC (Statistical Process Control) chart techniques were utilized to discover the comprehensive 3D-motion insights which then helped explain the bio-mechanisms associated with ACL injury risk.

Keywords
Anterior cruciate ligament, Sports injury, Biomechanics, Clustering, Multivariate SPC

1. Introduction
"STEM" (Science, Technology, Engineering, Math) and "STEAM" (Science, Technology, Engineering, Art, Math) are popular acronyms used to group together these academic disciplines (Gonzalez 2012, Marshall 2015). This term is typically used when addressing education policy and curriculum choices in schools to improve competitiveness in science and technology development. It has implications for workforce development, national security concerns and immigration policy. The acronym came into common use shortly after an interagency meeting on science education held at the US National Science Foundation. In the early 1990's, a summer program called STEM Institute arranged for talented under-represented students in the Washington, D.C. area. Based on the program's recognized success and expertise in STEM education, the NSF (National Science Foundation) was the first to introduce the acronym STEM.

1.1 Criticism of STEM
The focus on increasing participation in STEM fields has attracted many criticisms. Despite the efforts of the U.S. government to increase the number of STEM graduates, science and engineering occupations have been flat or slow-growing, and unemployment is as high or higher than many comparably skilled occupations (Teitelbum 2014). Additionally, some believe that the STEM crisis is a myth as some studies show that there is a "mismatch between earning a STEM degree and having a STEM job in the United States" as "only around ¼ of STEM graduates work in STEM fields, while less than half of workers in STEM fields have a STEM degree" (Charette 2013). Based on this data, science should not be grouped with the other three STEM categories, because, while the other three generally result in high-paying jobs, "many sciences, particularly the life sciences, pay below the overall median for recent college graduates (MacDonald 2018)." Efforts to remedy the perceived domination of STEM subjects has led to intense efforts to diversify the STEM workforce. Some critics feel that this practice in higher education, as opposed to a strict meritocracy, causes lower academic standards (Feldman 2015).

1.2 STEAM vs. STEM
STEAM fields include those in Science, Technology, Engineering, Art and Math (Matthiesen 2012, Anne 2014) and is designed to integrate STEM subjects into various relevant education disciplines. These programs aim to teach students innovation, to think critically, and use engineering or technology in imaginative designs or creative

approaches to real-world problems while building on students' mathematics and science foundations (Pomeroy 2012). STEAM programs add art to STEM curriculum by drawing on design principles and encouraging creative solutions.

1.3 Artificial Intelligence and Digital Art

In the modern big data society, artificial intelligence (AI) is emerging as a dominant field in the realm of data science. AI, machine intelligence, or machine learning stands in contrast to the natural intelligence displayed by humans. In computer science, AI research is defined as the study of "intelligent agents" such as any device that perceives its environment and takes actions that maximize its chance of successfully achieving its goals. Digital art is an artistic work or practice that incorporates digital technology as an essential part of the creative or presentation process. Since the 1970s, various names have been used to describe the process, including computer art and multimedia art. Recently, a lot of articles are interested in implementing AI in art and design such as feature imagery. This digital art application of AI is being referred to as 'generative,' and many expect generational AI to drive the next generation of apps for auto-programming, content development, visual arts, and other creative, design, and engineering activities. In generative graphics, AI can abstract visual patterns from artwork and then apply those patterns in the fanciful re-rendering of photographic images with the hallmark features of that artwork.

2. Breakdown of Six STEAMS Elements

Instead of using classical STEM or STEAM in this study, a new holistic “STEAMS” methodology is introduced. There are several novel concepts embedded in this new “STEAMS” methodology. “Art” is replaced with “Artificial Intelligence,” “Statistics” is separated from “Math”, and the key integration of all six “STEAMS” elements is extremely crucial in the successful implementation of this methodology. The concept of “STEAMS” (Science, Technology, Engineering, Artificial Intelligence, Math, Statistics) will be demonstrated through a case study on fatigue and ACL injury risk. The authors will break down the six STEAMS elements in the following sections.

2.1 Understand Basketball Sports “Science”

Basketball players’ strength can be categorized based on the SPARQ (Speed, Power, Agility, Reaction, Quickness) test. As seen in a recent study, the researchers used data from 234 of the 1092 players who participated in the NBA Combine from 2010-2015 which relates that player’s data to subsequent on-court NBA performance in each participant's first and third years. Using principal component analysis, a statistical analysis that finds the main or principal components of a dataset with a lot of variables, the three most important components can be identified as Body Length-size (height, standing reach, weight, wingspan, hand length, hand width), Power-Speed-Agility-Quickness (standing vertical jump, maximal vertical jump, ¾-court sprint, lane agility, body fat %), and Upper-Body Strength (bench press).

In the 2018-2019 NBA champion game series, the Golden State Warriors’ Kevin Durant suffered an Achilles rupture during game 5, and Klay Thompson tore his Anterior Cruciate Ligament (ACL) in Game 6. These two injuries have significantly impacted the new 2019-2020 NBA season and the near future. The ACL is located at the center of the knee joint from backside of the thighbone (femur) to front of shinbone (tibia). If the tibia is moved too far or hyperextended, ACL can be torn. Common causes include sudden deceleration, hyperextension, or pivoting in place where the foot is planted, and the body changes direction rapidly. Common sports that are source of ACL tears include basketball due to jumping, landing, and pivoting, football – planting foot and rapidly changing direction as well as body contact, and downhill skiing – the ski boots are worn higher than calf which moves the impact of a fall to the knee rather than the lower ankle or leg.

2.2 3D-Motion Sports Strength “Technology”

Modern technology has been popularly used in assisting athlete’s daily training and injury prevention. As seen in Figure 1, the 3D-motion analytics system places the sensors to monitor the motion patterns and muscle fatigue behavior. A sport-specific strength training program was built particularly on developing an athlete’s defense agility/speed using resisted band pulls (forward and side), plyometrics (jumping/explosive drills), cone agility drills, agility ladder, lateral lunges, and glute exercises. The core parameters identified to be in association with fatigue were the thigh angles, knee angles, hip angles, heel flattening on floor (when moving the weight away from toes or ball of foot), speed, and height (the taller the person, the more the fatigue minimizes knee bend).

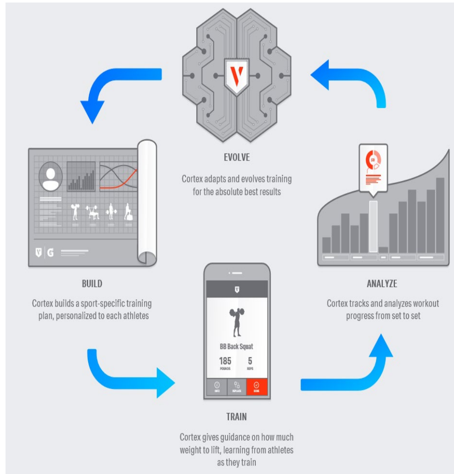

Figure 1. 3D-motion sports analyzer

2.3 Engineering Problem Solving

Stretching is an essential part of successful basketball as it helps minimize muscle imbalances, prevents injury, and improves basketball performance. There are three stages of warm up starting from the general warm up to get the blood flowing to all parts of the body including the cardiovascular system. A basketball warm-up may include jogging, stationary cycling or jumping jacks followed by dynamic stretching where the speed and intensity of your movement is increased gradually, and, finally, technical and speed warm up including high intensity, basketball specific drills. Drills for speed and agility should be kept short with recovery time between drills to ensure that the trainee is not fatigued. Additionally, designing an appropriate warm up program is critical to prevent sports injury. 3D-motion Analytics can track each athlete's motion and customize the warm-up program to test body readiness for further intense sports and minimize injury risk.

2.4 Artificial Intelligence

To further study the sports injury patterns, clustering variables technique was used to group the sports with similar injury patterns in Figure 2. Five clusters are identified, but this paper is particularly interested about the first three clusters (the first cluster consists of basketball, soccer, tennis, and figure skating, while the second cluster covers swimming and snowboarding, and the third cluster covers volleyball, golf, and weight lifting).

Cluster Members

Cluster	Members	RSquare with Own Cluster	RSquare with Next Closest	1-RSquare Ratio
1	Basketball	0.596	0.061	0.43
1	Soccer	0.53	0.158	0.559
1	Tennis	0.262	0.083	0.805
1	Figure Skating	0.596	0.017	0.411
2	Swim	0.514	0.022	0.497
2	Snowboarding	0.398	0.047	0.632
2	Wrestling	0.673	0.02	0.334
3	Volleyball	0.414	0.029	0.603
3	Golf	0.717	0.026	0.29
3	Weight Lifting	0.328	0.003	0.674
4	Football	0.568	0.07	0.465
4	Ice Hocky	0.568	0.069	0.464
5	Baseball	0.584	0.061	0.443
5	Kickboxing	0.584	0.011	0.42

Figure 2. Cluster members of 14 sports

Next, the sports injury locations were mapped in Figure 3. The injuries of the first cluster are mostly located at the lower body, especially at the knee location. When looking at the four sports associated with the first cluster (basketball, soccer, tennis, and figure skating), the strength of the lower body is crucial to preventing certain injury risk. The injuries of the third cluster are mostly located near the shoulder and upper body. The sports in the third cluster are volleyball, golf, and weight lifting which makes sense, as the strength of the upper body and shoulder muscle is critical to preventing the associated injury risk. The modern AI analytics techniques can efficiently provide powerful insights to injury patterns.

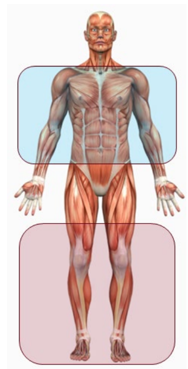

Figure 3. Focus of cluster 1 (blue) and 2 (red) injuries

2.5 Mathematics

In Section 2.4, "Artificial Intelligence" clustering patterns were identified based on the clustering distance mathematics of calculating the dissimilarity of nutritions among chocolate products. There are several cluster math algorithms including average, centroid, ward, single, and complete. These five different clustering algorithms have different join algorithms, so it is crucial to choosing the best method to explore the clustering patterns depending on the situation. The example in Figure 4 demonstrates how two of three existing clusters (green, yellow, and red) are going to join depending on the clustering distance algorithms for centroid, single, and complete. The centroid algorithm connects the green and yellow cluster as seen in the purple line connecting the two cluster means (represented using purple triangles). The single algorithm groups the green and red clusters by the closest points between these two clusters. The complete algorithm groups the yellow and green cluster as they are the farthest points between these two clusters. Depending on which distance algorithm chosen, the clustering sequence and pattern may be different, so the mathematical calculations for each clustering distance algorithm and a good understanding of the benefits and limitations of each math algorithm is crucial to determining the best algorithm in order to draw reliable clustering results.

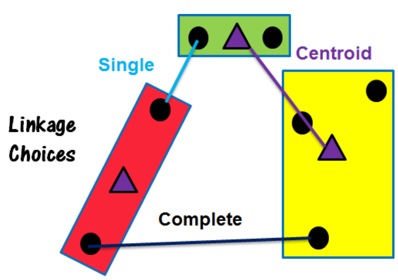

Figure 4: Diagram of the centroid, single, and complete clustering methods

The calculations of the five different clustering algorithms are shown in Figure 5. The basic algebra algorithms of the "Math" element are utilized in the modern "Artificial Intelligence" clustering method. In the new "STEAMS" approach, "Math" is the foundation of evolutions in the modern "Artificial Intelligence" field. Adding the "Artificial Intelligence" element can trigger a different direction of mathematical and scientific research.

Average Linkage Distance for the average linkage cluster method is:

$$D_{KL} = \sum_{i \in C_K} \sum_{j \in C_L} \frac{d(x_i, x_j)}{N_K N_L}$$ Average

Centroid Method Distance for the centroid method of clustering is:

$$D_{KL} = \left\| \overline{x}_K - \overline{x}_L \right\|^2$$

Ward's Distance for Ward's method is:

$$D_{KL} = \frac{\left\| \overline{x}_K - \overline{x}_L \right\|^2}{\frac{1}{N_K} + \frac{1}{N_L}}$$ ANOVA

Single Linkage Distance for the single linkage cluster method is:

$$D_{KL} = \min_{i \in C_K} \min_{j \in C_L} d(x_i, x_j)$$ Minimum

Complete Linkage Distance for the Complete linkage cluster method is:

$$D_{KL} = \max_{i \in C_K} \max_{j \in C_L} d(x_i, x_j)$$

Figure 5: 5 main clustering algorithm calculations

2.6 Statistics

Figure 6 has utilized the histogram distributions to compare the injury patterns across all four sports within the first cluster. All four sports have major injury risks at the lower body location. This visualization tool can further provide more injury insights, and the injury affinity pattern can help the physical therapist design a general training (such as strength or muscle development) program for several sports within the same cluster.

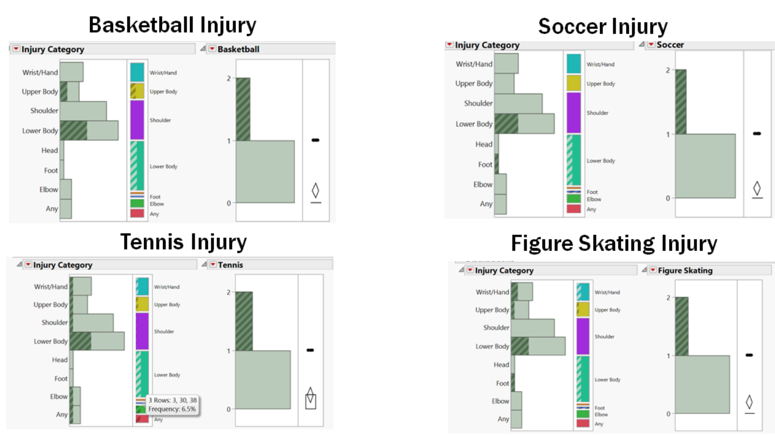

Figure 6: Histogram injury pattern analysis within the first cluster

3. Conclusions

"STEAMS" methodology was successfully implemented in this paper. First, the basketball sports science such how biomechanics relate to ACL injury risk was first studied through a systematic "Engineering" problem solving framework. "Artificial Intelligence" methods can help cluster sports injury patterns across 14 different sports, and Mathematics and statistics can help choose the appropriate analytics tools to uncover unique insights and draw more meaningful conclusions. In the Big Data era, most scientists and engineers should adopt this "STEAMS" methodology and integrate all 6 elements seamlessly to more efficiently solve any problems they encounter.

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Biography

Mason Chen is currently a student at Stanford OHS and serves as the student ambassador and webmaster for STEAMS. Having started STEAMS since its inception in 2014, he has held various roles such as President of the Student Chapter from 2017 to 2019. Through STEAMS, he has published more than 20 conference proceeding papers as first, second, or third author. As first author, he has won numerous awards including the Best Conference Proceeding Paper Award in the 2018 JMP Discovery Summit as well as finishing 1st Place three times for the STEM presentation competition at IEOM conferences. He has also certified the IBM SPSS Statistics Level I, II, Modeler Level I, and IASSC Yellow Belt, Green Belt, and Black Belt.