DEVELOPMENT OF POLE VAULTING SAFETY AND TECHNOLOGY

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Abstract: The purpose of this paper is to investigate the sport of pole vault and how it has changed. The history of pole vault is rich and the sport has changed greatly due to different techniques and ideas that have risen. These changes brought more injuries but they were later prevented with advancing technology. One of the leading causes of injuries was caused by athletes not landing on the safety mats. These pads have changed throughout the years to help prevent more injuries. Related equipment has also changed with the mats. This equipment includes the standards, cross bars, and box collar which have all evolved to help reduce the risk involved in the sport. One of the greatest increases in height and risk can be attributed to the change of material used to make poles. Pole vaulting technology and safety have advanced greatly throughout its history to create higher heights while attempting to slow the rate of injuries. This paper will discuss the history, technique, physics and technology of pole vaulting.

I. History and Background of Pole Vault

The beginning of pole vault competitions can be traced back to 1829 B.C. but it is believed the concepts of pole vault began in 2500 B.C. Ancient Egyptian artifacts and sculptures showed the use of poles to surmount enemy walls in warfare and to pass over irrigation ditches. It is also thought that the Egyptians used their vast knowledge of poles and lever systems to construct their massive pyramids and temples. Coming in the fifth century B.C., the Ancient Greeks created more evidence that they knew the concepts of pole vault. Paintings on vases recovered from this era depict the Greeks using spears or poles and using some of the same technique known today to jump onto or over objects. More evidence is provided by a writing from Johann Christoph Friedrich GutsMuths which provides details of a boy placing his spear in the ground and propelling himself into a nearby tree to escape his enemy. Pole vaulting then progressed into being practiced in competition in 1829 B.C. per the Irish Book of Leinster. These competitions took place in the Taliteann Games in Ancient Ireland until 554 B.C. The Middle Ages and the Renaissance were a mysterious time for pole vaulting because there was an 8-century time lapse before another mention of pole vault was found. The next recorded history can be traced to 1792 in the form of a book written by GutsMuths. He is considered by many as the father of modern pole vaulting. This is because he discusses jumping standards, general principles of pole vaulting, the distance of the approach, and recommendations on hand grip. From there, pole vaulting progressed to England and the United States in the 1800s. In 1826, Professor Voelker, a German gymnastics coach, had more than 1300 members at The London Gymnastic Society who competed in pole vault for distance and height [1]. Another early recorded vaulting competition was in 1846 at the Ulverston Football and Cricket Club. From here the sport began to grow and became a staple in the track and field world [2]. All but two states in the United States offer a scholastic championship. In 1877 the first collegiate pole vault championship was held. The National Collegiate Athletic Association (NCAA) started a men's outdoors championship pole vault event in 1921 and began another indoor championship in 1965. Women's pole vault was later added in 1998 and owns its own championships for indoor and outdoor [3]. Pole vaulting has developed greatly over different eras to where it is today.

II. How to Pole Vault

Pole Vaulting is an incredibly difficult and complex sport so it is broken down too many sections and explanations. Many coaches divide pole vault into seven different parts: (i) run-up, (ii) transition with arm elevation in the last three steps, (iii) take-off including the pole plant, (iv) swing phase, (v) rock-back, (vi) inversion position, and (vii) bar clearance [4]. The run-up is one of the most important parts of the jump. This is depicted in the picture

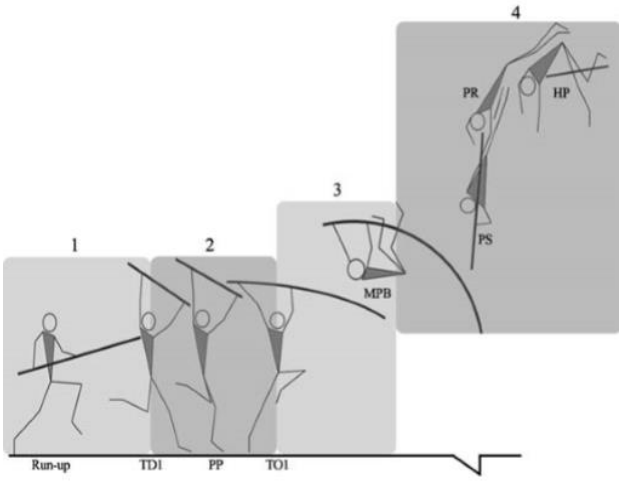

Figure 1: Pole Vault Progression [1]

as 1. The higher speed will lead to being able to jump on bigger sticks which leads to bigger heights. The transition with arm elevation in the last three steps (pole transition) and the take-off are shown in step 2 in the image. During these steps, the pole comes from the back of the hip to above the head and the tip goes into the plant box. The vaulter then jumps and runs off the ground which will begin to bend the pole and lead to the next steps. Those next steps are shown in the 3rd phase of the picture and are the swing phase and the rock back. Here the vaulter kicks or swings the trail leg toward the hands on the pole to end up in a pike position. From here the vaulter proceeds to the inversion and bar clearance shown in the picture in part 4. The athlete brings both feet up towards the crossbar and begins a turn towards their pole. They then are upside down with a straight body and push off the top of the pole. To avoid knocking the bar off, they pike over it and maneuver the top half of their body over the bar.

III. Brief Physics

Now knowing the basics of pole vault, basic elements of physics can be used to predict the height of a vault. The kinetic energy of a vaulter can be found if the velocity at take-off and mass are known. As the athlete runs down the run way, speed is increased and therefore kinetic energy also increased. After the take-off, the kinetic energy is transferred from the vaulter to the pole as it bends. As the pole begins to uncoil, the kinetic energy is transferred back to the vaulter in the form of gravitational potential energy which pulls the vaulter back down. Based on physics, the faster the vaulter is, the higher that vaulter can go [5]. The physics are a lot more complicated with all the equipment and moves involved in the sport. A general idea of what is happening with the energy is important to understand.

IV. Pole Vault Competitions

There are many places that one can acquire meet procedures and how to run a competition. Organizations like the NCAA, USA Track and Field Association, NFHS (National Federation of State High School Associations) will provide rule booklets upon request. There are some varying rules based on whether it is a college or high school meet but both sets of rules are nearly identical. Each competition has a starting height decided by the meet director based on athletes' entry heights. Any vaulter may decide to pass a height and open at a higher height. Any vaulter that passes three consecutive heights or doesn't vault for an hour is permitted two minutes of warmups without a cross bar or bungee. The vaulters progress heights typically of six inch increments until they have three consecutive misses. The last competitor then can decide what to place the bar at [6]. There are plenty of more specific rules on the vault but they can be found in the rule booklets.

V. Injuries

Injuries have been a serious concern in the sport of pole vault throughout its history. There are many things that can and will go wrong which lead to catastrophic injuries which are sometimes fatal. According to research data from National Center for Catastrophic Sport Injury Research (NCCSIR), from the fall of 1982 to the spring of 2012, there were 43 catastrophic injuries associated with high school pole vault. Since there are about 80,000 to 90,000 pole vaulters in high school, the catastrophic injury rate per 100,000 is 1.79. Pole vault is considered the most dangerous high school sport based on this data. Around 2.0 catastrophic injuries happened each year with 1.0 death on average in that time frame. Most of these injuries occurred when athletes landed or fell off the mats and hit mainly their head on the surrounding area. High school coaches and officials should be aware of this and keep trying to eliminate injuries caused by accidents like this. In 1983, there were three fatalities in the sport and it caused the National Federation of State High School Associations to act and implement new safety rules and guidelines. When a pole vaulting fatality or serious injury occurs, more people begin to question why the sport is in existence and why it is still offered in high school. Most of the opposition comes from the amount of liability involved with pole vault and the lack of qualified coaches to teach the event [7]. Other studies used the research data from 1982 to 1998 gathered by the NCCSIR to conduct their own studies. One of the studies found people related to the 32 catastrophic injuries that happened in this period and asked them questions to receive further data. In most cases the coach was interviewed but in other cases it was the athlete, a family member, trainer, or athletic director. In all the catastrophic injuries studied, they were all sustained by male vaulters with an average age of 17.5 years (14 to 23). 78 percent of the injuries happened in high school and 9 percent occurred in college. The other

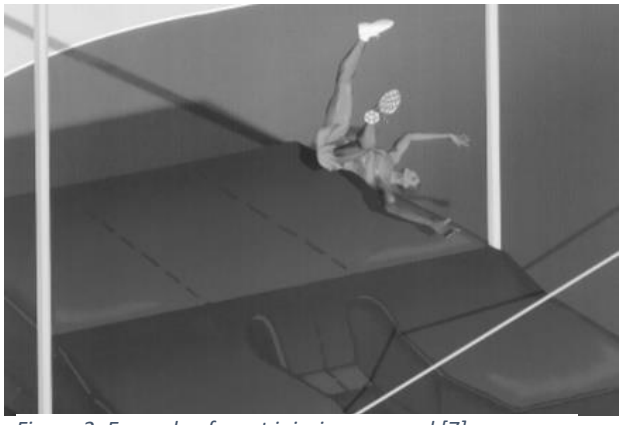

Figure 2: Example of most injuries occurred [7]

13 percent of catastrophic injuries were sustained in junior college, junior high school, medical school, and one by a high school coach. Of all the injured athletes, there were only three means by which they sustained their injuries. Figure 2 shows how most of the injuries happened. 53 percent of the time the pole vaulter landed with his body on the edge of the mats and his head coming off the pad which would strike the surrounding hard surface. Most of the time it was unprotected concrete or asphalt which caused the injury. The second most amount of injuries had a 25 percent occurrence. This happened when vaulters released the energy in the pole too early or did not have enough momentum causing them to land in the box. In the remaining cases, the athlete completely missed the landing mats and hit the hard-surrounding surface. Of the 32 injuries recorded, 31 of them were serious head trauma/injuries and one thoracic spine fracture which resulted in paraplegia. Other injuries and complications could have been sustained by the vaulter but the main data only includes catastrophic injuries [8]. One study was completed by the Medical College of Wisconsin that looked at injuries of high school pole vaulters over a year. The data was collected during the 2005-2006 season from 140 athletes. The injury rates in this time was found at 26.4 injuries per 100 athletes. 70 percent of the injuries were to the lower extremities. Figure 3 shows where the injury occurred and figure 4 shows descriptors of how and where the injuries were sustained. The injuries in high schoolers are expected to be high due to the inexperience of many vaulters [9].

Location[a]	N (%)
Upper extremity	
Shoulder/arm	1 (2.6)
Forearm/wrist/hand	2 (5.3)
Lower extremity	
Hip/thigh/hamstring	5 (13.2)
Leg	5 (13.2)
Knee	6 (15.8)
Ankle	10 (26.3)
Foot	1 (2.6)
Back/spine	
Thoracic	2 (5.3)
Lumbar	6 (15.8)
Types[b]	
Sprain	12 (31.6)
Strain	10 (26.3)
Contusion	7 (18.4)
Internal derangement of knee	2 (5.3)
Fracture/stress fracture	2 (5.3)
Dislocation/subluxation	1 (2.6)
Laceration	1 (2.6)
Overuse	3 (7.9)

[a]No head/neck/face or chest/abdomen injuries were reported.
[b]No concussions or dental trauma were reported.

Figure 3: Location of injury on body and what type [8]

To see if experience has a difference on injuries, the same group conducted a study on the injury patterns in collegiate pole vaulters. The same process was used but this time with 135 collegiate vaulters. The data showed that college athletes experienced more frequent injuries at 41.5 per 100. This increase can possibly be attributed to longer seasons and higher training intensities. The same data collected for high school vaulters was collected for college pole vaulters. In figure 6 it shows location and type of injury and in figure 5 it shows how and where the injury happened [10]. Following rule changes in 2003, data was kept to see how the rule changes helped. From 2003 to 2011, there were 19 catastrophic injuries but there were fewer deaths. The death per year rate fell from 1.0 to 0.22. Most injuries changed from falling off the back or side of the mats to falling in or around the plant box. This remains a huge issue in the cause of injuries [11].

Mechanism	N (%)
Landed awkwardly in pad	10 (26.3)
Missed landing pad	7 (18.4)
Plant/take-off/swing-up	6 (15.8)
General stress	6 (15.8)
Running	3 (7.9)
Fell through gap in landing pad	2 (5.3)
Struck by crossbar	2 (5.3)
Pole-plant drill	1 (2.6)
Caught foot in plant box on run-through	1 (2.6)
Event Variable	
Practice	27 (71.1)
Competition	11 (28.9)
Pole-vault drill	26 (68.5)
Full vault attempt	12 (31.5)
At or above PR	5 (42)
Below PR	7 (58)
Increased grip height	3 (7.9)
Increased pole weight	2 (5.3)
Indoor track	9 (23.6)
Outdoor track	28 (73.7)

[a]PR, personal record for height clearance.

Figure 4: How injury happened and in what situation [8]

Injury Mechanisms (N = 70 Injuries)

Mechanism	No. (%)
Vaulting	47 (67.1)
Approach	8 (11.4)
Swing up	4 (5.7)
Plant/takeoff	23 (32.8)
Landed awkwardly	3 (4.3)
Landed on pole	1 (1.4)
Landed on bar	1 (1.4)
Missed pit	6 (8.6)
Unknown	1 (1.4)
General stress	18 (25.7)
Other	5 (7.1)
Pool drill	1 (1.4)
Sprinting	2 (2.8)
Bounding	2 (2.8)

Figure 5: College vaulter injury occurrence and situation [9]

	No. (%)
Location[a]	
Upper extremity	
Shoulder/arm	6 (8.3)
Elbow	3 (4.2)
Forearm/wrist/hand	6 (8.3)
Lower extremity	
Hip	2 (2.8)
Quadriceps	3 (4.2)
Hamstrings	10 (13.9)
Knee	4 (5.6)
Leg	10 (13.9)
Ankle	7 (9.7)
Heel/foot	7 (9.7)
Abdomen	1 (1.4)
Back/spine	
Thoracic	1 (1.4)
Lumbar	12 (16.7)
Type[b]	
Strain	27 (37.5)
Sprain	13 (18.1)
Stress reaction[c]	10 (13.9)
Tendinitis	8 (11.1)
Stress fracture[d]	7 (9.7)
Contusion	5 (6.9)
Acute fracture	1 (1.4)
Laceration	1 (1.4)

[a]No head/neck/face or chest injuries were reported.
[b]No concussions or dental trauma were reported.
[c]Includes shin splints.
[d]Includes spondylolysis.

Figure 6: College vaulter injury location and type [9]

VI. Pole Vaulting Poles

Pole vaulting poles have advanced greatly throughout the sport's history. They were first made of hard-woods like ash or hickory. These poles were extremely heavy and rigid which means they would not bend and were hard to maneuver. Their rigidity also did not allow the transfer of energy from horizontal to vertical easily. This limited early height because so much energy was lost during the vault. From the hardwoods, poles transitioned into the bamboo era. These poles were hollow so they were much lighter. They also had some ability to bend when stressed. Both these factors allowed more energy to be created and transferred upward in the vault which allowed them to go higher than before. The highest height achieved on a bamboo pole was 4.77 meters. Poles shifted to being made from aluminum during the 1950's and 1960's but the next advancements of poles came quickly. The new poles were made from fiber glass and carbon fiber. These materials revolutionized the sport [12]. Many factors are considered when designing poles: strength and rigidity, carry weight, mandrel size, stiffness and safety, and plenty of others. Engineers use formulas and calculations to determine what size and patterns to use to make different poles. The way poles are made is that a pattern is cut from fiberglass or carbon fiber. These layers are wrapped around a metal mandrel and then baked in ovens with heat and pressure. This melts and cures resins in the pole so that it gains all properties. Poles then enter a cooling process which hardens and solidifies them. They are then flexed on a machine to determine the weight rating for the length pole created. After this they are wrapped in a protective tape and given labels and are ready for sale [13]. These poles are stronger, lighter, more flexible, and more responsive than previous poles that were used. They are continually being refined today by various manufacturers. Although they are continued to be refined, pole vaulting poles have led to the sport reaching a plateau. The heights have not increased greatly over the last 20 years because of the limit in technology and athleticism [12]. Pole vault poles are a costly item that range from around $300 to over a $1000 for specialty poles. There are many manufacturers related to the sport of pole vault which include: Altius, ESSEX PV, Gill Athletics, MF Athletics, Nordic Sport, On Track, and UCS Spirit [14].

VII. Pole Vault Pit and Box Collar

Pole vault landing systems have advanced greatly since the start of competitions. They originally began as heaps of sawdust or sand that the vaulters would land in feet first. This worked at first but as new technology was created. There was a need to create a safer landing system. This led to large chunks of foam being put into bags for the landing system [15]. Later, these chunks of foam were turned into landing mats when the founder of the company UCS Spirit was asked to repair a previous pit. He saw the need for a safe and portable landing system and produced the first of

Figure 7: First pole vault mat system at National AAU championships in Oregon in 1970 [15]

its kind. He then took this pit across country to the National AAU Championships in Oregon. Here the pit was supposed to be displayed but was used in competition which can be seen in figure 7. This led to the pit being bought by the Oregon Track Club and the founder of UCS Spirit has since continued his success making track and other equipment [16]. There are various producers of equipment today as mentioned in the previous pole vault poles section. The mats today are continually growing to help prevent injuries. There are now mandated rules on the minimum size pit, the surrounding pit area, and the box collar that can be used. Following the deaths of three athletes in 2002, the NFHS enacted a few key rules to increase pit size from 16 feet wide by 12 feet deep from the back of the box to 19 feet 8 inches wide by 16 feet 5 inches deep. NFHS also now required that hard surfaces surrounding the landing pads be removed or padded with at least two inches of dense foam or other suitable material [11]. Another change made was to the requirement of a new box collar in 2013. The new box collar was designed with wings that extended over the edge of the box. This was designed to help prevent catastrophic injuries that happened by falling in the box [17]. Other changes throughout the years are requiring that standards, which hold the crossbar, can only be placed from 18 inches to 31.5 inches. In 2009, there were six states that required helmet use in high school pole vault: Maine, Minnesota, New Mexico, North Dakota, South Carolina, and Wisconsin. These states later got rid of the requirement and it remains the athlete's choice. Arguments against helmets were that they are not guaranteed to stop serious injury. Also, they may give the vaulter a false sense of security which may lead to poor choices [3].

VIII. Conclusion

Pole Vaulting is very complex sport and has a very rich history. It has progressed from ancient times as a useful transportation tool to a competitive track and field sport today. Pole vault technique can be broken down into different phases and is very difficult to master. The basic physics of the sport will help some athletes learn how to pole vault but the real physics are incredibly complicated. Competitions are also difficult to understand until participated in. One major downfall of the sport is the risk of injury. There have been many catastrophic injuries in the past and these continue to happen today. Studies have been done on high school athletes and college athletes to determine injury types and rates. One thing that has improved in the sport is the technology. Poles have advanced greatly and now have a lot of engineering work put into them to improve performance. Other advancements include the mats and box collar. There have also been many rule changes that have occurred in attempt to help reduce catastrophic injuries and injuries in general.

IX. References

1. Johnson, Jan, Russ VerSteeg, and Ray Kring. *Illustrated history of the pole vault*. Norwich, CT: S.n., 2007.
2. Ganslen, Richard V. *Mechanics of the pole vault.* St. Louis: Swift, 1980
3. Bemiller, J., & Hardin, R. (2010). Risk management in the original extreme sporting event: The pole vault. Journal of Physical Education, Recreation & Dance, 81(2), 23-28. Retrieved from https://search.proquest.com/docview/215758499?accountid=42681
4. Frère, Julien, Maxime L'Hermette, Jean Slawinski, and Claire Tourny-Chollet. 2010. "Mechanics of pole vaulting: a review." *Sports Biomechanics* 9, no. 2: 123-138. *Academic Search Premier*, EBSCO*host* (accessed February 20, 2017).
5. Blanchonette, Peter, and Mark Stewart. "The Science of Pole Vaulting." Quantum11, no. 5 (May & June 2001): 48-54. Academic Search Premier, EBSCOhost (accessed February 20, 2017).
6. Blackburn, John C., ed. USATF Track & Field Rules 2017. Indianapolis, IN: USA Track & Field, 2017.
7. Mueller, Frederick O., Kristen L. Kucera, Leah M. Cox, and Robert C. Cantu. Catastrophic Sports Injury Research. Report. National Center for Catastrophic Sport Injury Research, The University of North Carolina at Chapel Hill. 23-24.
8. Boden, B.P., P. Pasquina, J. Johnson, and F.O. Mueller. 2001. "Catastrophic injuries in pole-vaulters. / Blessures graves chez les perchistes." American Journal Of Sports Medicine 29, no. 1: 50-54. SPORTDiscus with Full Text, EBSCOhost (accessed February 21, 2017).
9. Rebella, Gregory S., Jamie O. Edwards, Joseph J. Greene, Mark T. Husen, and David C. Brousseau. 2008. "A Prospective Study of Injury Patterns in High School Pole Vaulters." *American Journal Of Sports Medicine* 36, no. 5: 913-920. *SPORTDiscus with Full Text*, EBSCO*host* (accessed March 7, 2017).

10. Rebella, Gregory. 2015. "A Prospective Study of Injury Patterns in Collegiate Pole Vaulters." *American Journal Of Sports Medicine* 43, no. 4: 808-815. *SPORTDiscus with Full Text*, EBSCO*host* (accessed March 7, 2017).
11. Boden, Barry P., Matthew G. Boden, Rebecca G. Peter, Fred O. Mueller, and Jan E. Johnson. 2012. "Catastrophic Injuries in Pole Vaulters: A Prospective 9-Year Follow-up Study." *American Journal Of Sports Medicine* 40, no. 7: 1488-1494. *Academic Search Premier*, EBSCO*host* (accessed March 7, 2017).
12. McCormick, Matthew. "Soaring to New Heights: The Evolution of Pole Vaulting and Pole Materials." Illumin. June 2010. Accessed February 21, 2017. http://illumin.usc.edu/printer/143/soaring-to-new-heights-the-evolution-of-pole-vaulting-and-pole-materials/.
13. Watry, Jeffrey. "The Pole Vault Pole: An Engineer's Perspective." GIll: 1-10. Accessed March 01, 2017.
14. "Pole Vaulting Equipment Manufacturers - USA Pole Vaulting." USA Pole Vaulting. Accessed February 21, 2017. http://www.usapolevaulting.org/manufacturers.htm.
15. "Pole vault." New World Encyclopedia. Accessed March 07, 2017. http://www.newworldencyclopedia.org/entry/Pole_vault.
16. "The UCS Story: Lou's Legacy." Family Company | UCS Spirit. Accessed March 07, 2017. http://www.ucsspirit.com/about/family-company.cfm.
17. Burnsed, Brian, and Greg Johnson. "NCAA, USA Track & Field and NFHS Come Together for Pole Vault Safety." The Official Site of the NCAA. October 13, 2014. Accessed March 07, 2017.http://www.ncaa.org/health-and-safety/sport-science-institute/ncaa-usa-track-field-and-nfhs-come-together-pole-vault-safety.