The Philosophy of Developing Pitchers at Galaz Baseball Technologies (GBT)

Introduction

At GBT, our first priority is to keep our pitchers healthy while improving performance (accuracy & velocity. While there is a misconception of misunderstanding that the three can be attained simultaneously, we at GBT developed a methodology called **the three I's to pitching success system (TIPS)** that has achieved successful results for over 25 years. The main ingredient for this success of TIPS has been due to a thorough understanding and application of physics principles. When we talk about physics also includes the mathematical and geometrical interpretation of how the pitcher moves to attain TIPS. A deeper understanding can explain why pitchers are sustaining injuries to the shoulder and elbow at an increasing rate.

The status quo gravitates to increasing velocity – accuracy and injury prevention take a back seat. Accuracy and injury prevention take a back seat because it is the standard the MLB and colleges use to select young prospects. So those that pitch with higher velocities are chosen over those that do not. As mentioned earlier, all three can be attained at the same time.

Throughout this literature, how we develop pitchers at GBT is explained in detail and in order using physics interpretation when needed. In addition, 16 skills will become of the expounding on TIPS.

The Three I's to Pitching Success System

I #1 – Injury prevention

- It is evident that injury keeps pitchers from success
- Injuries are avoided with sound movements and proper shoulder and elbow positioning
- Injuries are avoided with adequate physics knowledge understanding of how to reduce forces to reduce stresses in the shoulder' and elbow's connective tissue
- Some injuries are chronic and may be due to underlying issues such as
    - **Poor mechanics**
        - Poor posture during the motion
        - Poor acceleration phase
        - Too short of a stride
        - Poor deceleration phase
        - Pitchers not moving in simple harmonic motion (SHM) & resonant frequency (RF)

A clarification concerning observing SHM and RF is critical for maximum energy transfer. Everything globally has its resonant frequency (RF) of movement or vibrates, also called the natural frequency (NF). RF and NF are equal as long as there is no dampening or decreased amplitude in a system – RF and NF are interchangeable. RF is when a system can store and easily transfer from one energy form to another. Such as potential energy (*PE*) (stored energy), also known as elastic energy, which converts to kinetic energy (*KE*) (energy of motion) in an oscillating system due to the conservation of energy principle, such as a system oscillates at its natural or unforced resonance.

- **Poor stability**
    - Poor posture produces instability throughout the motion
    - Instability is one of the major causes of

injury due to poor positioning of the shoulder and elbow joints
  - **Neuromuscular dysfunctions** or **muscle imbalances** that limit mobility
    - Scapular dyskinesia
    - Thoracic outlet syndrome
    - Shoulder instability, to name a few

I #2 – Improving accuracy/command

- Without a doubt, the best pitch in baseball is a well-located fastball
- The status quo gravitates to increasing velocity than improving accuracy, although both are attainable simultaneously using the TIPS mentioned earlier.
- Poor accuracy is due to
  - **Poor mechanics**
    - Poor posture during the motion
    - Limited trunk forward rotation
    - Poor leveraging system
    - Truck and arm not moving as one link
    - Not a long enough stride
    - Not enough follow-through after release
  - **Poor stability**
    - Inability to stay aligned to the target
    - Due to poor posture
  - **Pitchers not trusting their hand-eye coordination**
    - Pitchers try to steer the ball to a location, especially in tough situations
    - Pitching mechanics change when pitchers do not have confidence in what they have learned

I #3 – Increasing velocity

- As mentioned earlier, velocity is desired above all else, but velocity and accuracy can be improved at the same time with TIPS (velocity & accuracy go hand in hand)
- Velocity is improved by increasing the leverage system the pitcher produces
- Velocity is improved with proper interpretation and application of physics principles
- Poor velocity is due to
  - **Poor mechanics**
    - Poor posture during the motion
    - Limited trunk forward rotation
    - Poor leveraging system
    - Trunk and arm not moving as one link
    - Not a long enough stride
    - Not enough follow-through after release
  - **Poor dynamic balance (will use balance to mean dynamic balance in this material)**
    - Pitcher not able to maintain good **posture** by not centering the center of gravity (CG) to the

base of support (BoS)
  - Pitcher not able to produce maximum momentum
  - Affects the stability of the push-off leg and the landing leg
- **Poor stability**
  - Pitcher not able to produce maximum impulse from push-leg
  - Pitcher not able to transfer total momentum up the kinetic chain efficiently

Balance and **stability (B&S)** having to do with human movement are sometimes used interchangeably but have different meanings.

"Suppose somebody is shooting a cannon from a canoe. The canoe may be balanced; it may even remain balanced while the cannon is on board. The canoe, however, does not have the stability to remain in its position when the cannon is fired. In a similar manner, our bodies need a stable base in order to be able to produce force in a manner that is effective. If your body is more stable, you are able to shift more weight or produce more force in a more efficient and effective manner." ***Chris Slaviero****, Author, Practice Principal at Physio Inq South Penrith.*

The 16 Skills Developed from TIPS

These 16 skills help pitchers improve their performance (improve accuracy & velocity) while preventing injury. As mentioned earlier, there is a misconception that improving performance and preventing injury at the same time is not possible. Furthermore, pitchers are posed a choice whether to improve accuracy or increase velocity? The latter wins out every time. The good news is that the TIPS has been proven to prevent injury while improving performance simultaneously.

Although all pitchers should pitch from the wide-up and stretch, the 16 skills start when the pitcher lifts his stride leg.

1. **Leg Lift**

- The **leg lift** is the first skill to master to flow properly in the kinetic chain sequence to create proper alignment with both feet (heel to heel).
- The **leg lift** must be activated primarily by the hip flexor muscle (psoas) and no contraction in the quadricep or dorsiflexion at the foot. The front leg must be relaxed throughout the lift, where the only contraction is at the hip flexor muscle.
- The **leg lift** must be as high as possible while not negatively affecting posture.
- The **leg lift** movement must be fluid and not rushed.
- The leg **lift leg** must not swing over past the post leg before moving toward home plate (HP).

It is essential for producing maximum energy and momentum consistently throughout the entire pitching motion (PM).

2. **Posture (PDP)**

- **Posture** corresponds to dynamic balance and stability in any action the body is involved in from start to finish. Correct posture allows the body to produces optimal outputs due to the correct CG position. In other words, the closer the CG is to the center of the body throughout the

PM, the higher the efficiency of the output (accuracy & velocity).

- Proper **posture** plays a vital role in creating and maintaining adequate alignment toward HP.

- Good **posture** is performed correctly when the trunk is slightly over the front leg lift thigh, ensuring the CG is directly underneath the pitcher.

- Good **posture** assists in obtaining correct arm action.

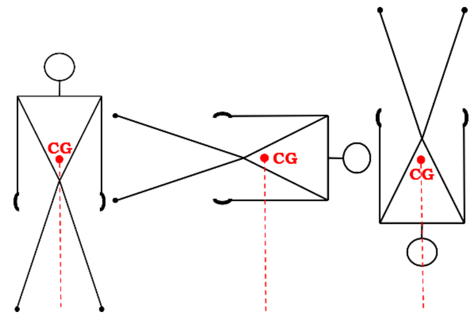
- Proper **posture** leads to keeping the shoulder and elbow healthy.

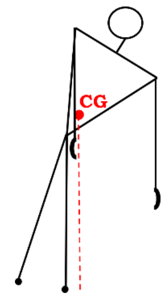
Posture is an essential attribute in most sports. **Posture** rarely is discussed in pitching mechanics – the optimum positioning of the CG that assists in producing maximum power. In addition, it allows the core to stay engaged as the pitcher throughout the push-pull stages for maximum momentum generation.

Good Posture Attained by Improving B&S

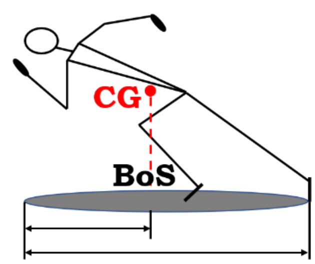
To demonstrate how to improve **B&S**, the terminology to communicate this concept must be developed.

Gravity is the force that attracts an athlete's body with mass to the center of the earth, and **CG** is the theoretical balance point (moves as the body moves and can be outside the body depending on the movement) of the athlete's body without a tendency to rotate or tip over. Also, the center around where the body can rotate freely in all directions. In the following first three images, the **CG** is positioned where the body cannot rotate or tip over unless the **CG** moves outside the body, which can only happen if the upper body leans left or right, as shown in the last image. The second and third images illustrate that the **CG** is the center or axis of rotation of the body is to rotate freely in any direction.





Since the **CG** is an imaginary point in space that moves outside the body corresponding to the direction of motion, in the case of a runner, the athlete moves the **CG** to the left side of the **BoS** to move in that direction. The **BoS** is the shaded area underneath the runner's body, as shown below.

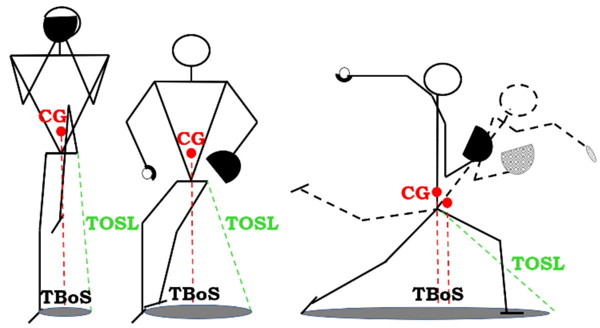


Therefore, in athletics, the **CG** is positioned in a certain way to optimize the required movement. The **CG** acts in the direction of gravity perfectly plumb down to the center of the earth regardless of the orientation of the athlete's body. Therefore, irrespective of the position of the body, the **CG** always points straight down. So the athlete's objective is to position the **CG** in an optimum location beneath the body to accomplish their ultimate goal. Also, lowering the **CG** helps stabilize the athlete before starting. So depending on the athlete's task, he moves the **CG** forward, middle, or the back of the **BoS**.

As mentioned earlier, the idea of applying **B&S** is an essential element for improving pitching performance while reducing the chances of injury. **B&S** work together to ensure that a pitcher can control his body's equilibrium throughout the PM. Although closely related, some use them interchangeably, but they differ in their meaning. **Balance** is the pitcher maintaining his equilibrium while not fighting gravity, letting gravity be the pitcher's friend as the **CG** stays as centered as possible on the **BoS** from the start of the PM to just before the push of the back leg to the landing of the front foot. In comparison to **stability**, the pitcher contends with a disruption of his equilibrium as he propels himself forward due to the force production from the push of the back leg. While maintaining **stability**, similar to **balance**, the pitcher is still trying to keep his **CG** centered while maintaining his trajectory toward home. It can be said that **stability** helps **balance**. In other words, if the pitcher has good **stability**, he has better **balance**. When referring to the **B&S** of a pitcher, it is equivalent to denoting **PDP** used going forward instead of **B&S** unless alluding to one or the other individually. Also, when **PDP** is mentioned, **CG** must be considered as central to the **BoS** as possible, as mentioned earlier about **B&S**. **PDP**, sound or poor, determines each movement the pitcher makes, which means the body automatically compensates for any postural deficiencies.

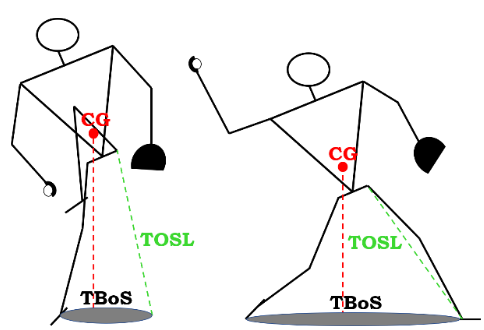
Applying a force or torque must be made with a good **BoS** and proper throwing posture to increase velocity safely. Thus, producing a force or torque while in a poor posture increases the risk of injury to the shoulder and elbow joint, which requires these two joints to absorb most of the acceleration and deceleration loads.

The following images illustrate how adequate **balance** is maintained throughout the PM. Per the definition of **balance**, which stipulates: the pitcher is to control his equilibrium without fighting gravity depicted by the **CG** centered to the **BoS** from the start to just before the throw. There is a minimal to no **contralateral tilt** of the trunk (trunk leaning back during forward motion).



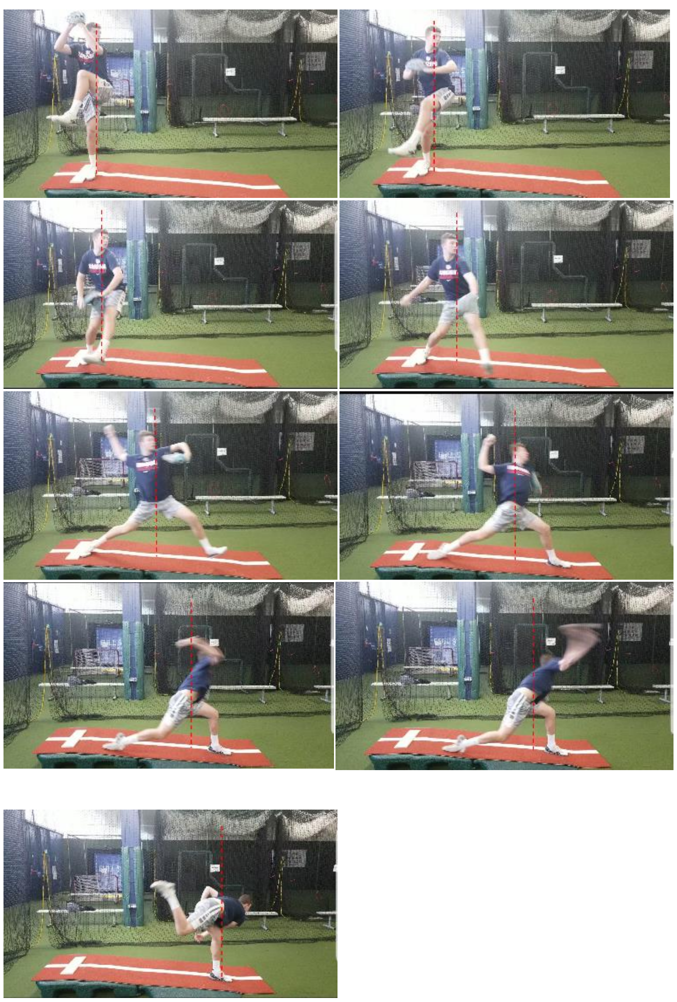
It is counterproductive to produce any force or torque when the **CG** is not somewhere near the middle of the **BoS**. **Stability** is also demonstrated by a green **theoretical opposite stability leg (TOSL)** that points out that if we assume where the front leg would land at each movement position, the **CG** would be centered on the **BoS**. This is called the **theoretical base of support (TBoS)** since the definition of **BoS** requires two feet on the ground. Since the pitcher has created momentum to where he is in the last image, that momentum continues up the kinetic chain from the front leg through the trunk to ball release more efficiently.

In the next series of two images, the pitcher starts his motion with a severe **contralateral trunk tilt**, which positions the **CG** left of the center of the **BoS**.



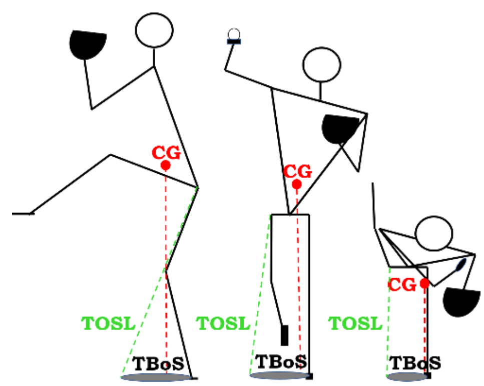
In the last images of the previous two series of pitcher movements, the **TOSL** became the theoretical opposite stability leg since the front foot hit the ground per the **BoS** definition. Also, the **TBoS** became the actual **BoS**, again, since the front foot hit the ground.

As mentioned earlier, the definition of **gravity** tells us that the **CG** location is an imaginary point in space that may or may not move outside the body per motion requirements. During the PM, awareness of where the **CG** is positioned is essential for pitching efficiency, and not much information is out there that implements this concept in pitching methodologies. Although command is an important skill to have, all pitchers covet more velocity. Improving velocity requires good foot alignment, and where the **CG** is located close to the middle of the **BoS** throughout the entire PM until release is vital. Therefore, it is essential that the **CG** does not lag too far behind the pitcher's centerline, and his centerline is pretty much the **CG** red line, as shown in the pitching sequence below.



A **CG** that lags too far behind the pitcher's centerline does not allow the total usage of the back leg drive. Therefore less energy is being put on the ball.

This notion can also be demonstrated from the front view – the difference in this view, the **CG** drifts toward the landing leg throughout the entire PM. The **CG** almost aligns with the landing foot, and for a good reason. Ideally, the front leg should line up with the back leg at landing if proper alignment is maintained for accuracy. Suppose the pitcher can land in this position shown in the last images below. In that case, he should be able to hold his balance over the front leg for 3 seconds or more. Holding this position for several seconds over the landing leg and pitching at full speed is a good indicator of adequated **PDP**. This concept is also illustrated in the last image of the pitching sequence across the page. Holding this position for 3 or more seconds during bullpens is an excellent drill to improve **PDP**.



The ability of an athlete to control his **stability** as gravity acts on them is essential while maintaining **PDP** during movement, which means that if the **CG** stays within the **BoS**, preferably the center of the **TBoS**, **PDP** is supported.

3. **Alignment**

- **Alignment** is crucial when it comes to **preventing injury**. Poor alignment affects posture, which in turn causes the arm's position to be altered to redirect the ball back to the target at midstride, compromising the shoulder and elbow.

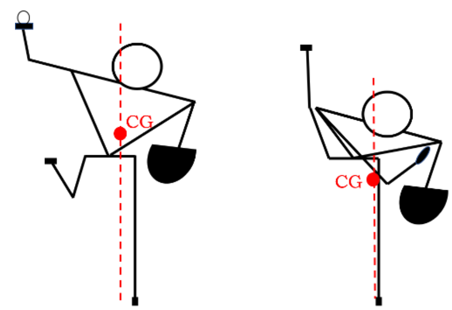
- **Alignment** is one of the most critical keys for throwing for **accuracy**. Accuracy is a skill used by those that compete in hitting a target, whether the center or otherwise. For pitchers, it starts with the alignment of the feet. If a right-handed pitcher stride 10 inches off-center or more, the upper body must redirect the ball by altering posture, affecting dynamic balance and stability (covered later). Balance and stability are vital for accuracy.

- **Alignment** is essential for increasing **velocity**. For increasing velocity, momentum must be created in the line of action directly to where the ball is thrown. If the alignment of both feet is 10 inches or more off-target, the momentum of the pitcher's body must redirect back to the target, where the pitcher must throw across his body to do so. When diverting momentum, some of it is lost, losing velocity. The velocity decreases because momentum is the product of the mass m and velocity $\boldsymbol{v}$. Since the mass is constant throughout the motion, the momentum can only decrease if the velocity decreases. Therefore, momentum and velocity are directly proportional. In other words, if one increases, the other also increases, and if one decreases, the other decreases. The relationship of linear momentum is $\boldsymbol{P} = m\boldsymbol{v}$.

The best pitch in baseball is undoubtedly a well-located fastball. It is challenging to get hitters out if pitchers cannot throw strikes and adequately locate the fastball, making their secondary pitches more effective. Alignment and accuracy are, in a sense, synonymous, but you need better alignment to produce accuracy.

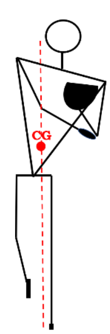
<u>Proper Alignment Toward HP</u>

A good visualization of how a pitcher keeps the ball on the target longer is to draw a line down the middle of the pitcher's body just as he lands with his front foot. Let us say that the line is where the CG drops to the ground, as shown below.



The more he keeps bending over his front thigh, keeping his truck and arm moving as one link as long as possible, the longer the ball stays on the throwing arm side of the red centerline, as viewed from the front. Hence, improving accuracy.

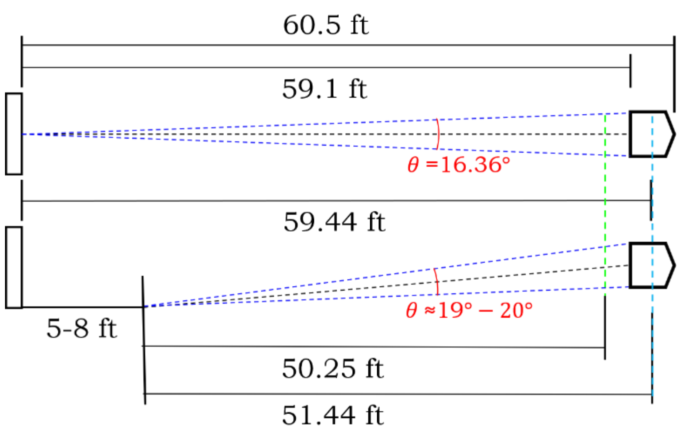
Most teach to post up the front leg, making it challenging to continue bending unless the pitcher is hypermobile in the hamstrings. Therefore, the throwing hand crosses the red center line too early, pulling the ball off target, as shown in the image below.



When pitchers post the front leg causes several issues.

- It puts the landing leg's hamstring in a compromising position to be pulled or torn
- The shoulder is forced to do most of the acceleration and deceleration of the arm
- It causes accuracy problems
- It reduces velocity
- It reduces pitch count since the pitchers' arms fatigue sooner
- It reduces the effectiveness of the entire bullpen

Therefore, keeping the ball on the arm side longer before release improves a pitcher's accuracy. This fact is illustrated using the following image, as we look from a top view of the rubber and HP.



The obvious distance is from the rubber to HP at 60.5 ft. The measurement is from the front of the rubber to the back of HP. The 2nd measurement is from the distance from the front of the rubber to the front of HP. 3rd is the distance from the front of the rubber to the center of HP. The distance of interest is at the pitcher's release of the ball 8 feet in front of the rubber; the hitter tries to make contact with the ball in front of HP at 50.25 feet away from the release. It should be apparent that if hitters have less time to see the ball, releasing it closer to HP is a big part of deceiving the hitter. A little number crunching illustrates this fact by using ratios. We use the ratio below to calculate the perceived velocity from the hitter view of a 90 mph fastball released 8 ft in front of the rubber.

$$\frac{90\ mph}{50.25\ ft} = \frac{x\ mph}{1\ ft} \implies x = 1.80\ mph$$

Each foot closer to HP makes the perceived velocity 8 ft times 1.80 mph, which equals 14.33 mph faster than 90 mph, so the hitter perceives it as a 104.33 mph fastball. As the velocity increases from the pitcher, so does the perceived velocity per ft. A 95 mph fastball would be perceived to be a 110.12 mph fastball. In this case, we have to give the hitter credit to get to a perceived 104 mph or 110 mph fastball, which is why pitchers need to release the ball further in front of the rubber to stay ahead of hitters.

The angle θ has significance from the standpoint that the pitcher's hand at release can stay in the same position as he moves the ball in and out at HP. Also, pitchers that can make the ball come out of the same arm slot are the most successful at any level of baseball.

As mentioned earlier, the best pitch in baseball is a well-located fastball. Secondly, pitchers must be able to command their off-speed pitches. They must understand that their off-speed pitches have two targets; where to start the pitch and where they want it to finish. This is possible if the throwing arm stays on its side as long as possible, ensuring all of the pitches in the pitcher's arsenal hit the target with more consistency, as demonstrated in this material.

4. Arm Action

- Correct **arm action** assists in reducing the risk of injury. If the arm action moves forward due to continual trunk rotation (arm is along for the ride), it constitutes safe arm action. On the contrary, if the arm action is independent of trunk rotation, the arm is doing most of the work, increasing the chance of injury.

- Proper **arm action** is essential for several reasons, as the sling of a trebuchet is considered a very efficient energy transfer system. The same goes for the pitcher's arm throughout the pitching motion. One of the trebuchet's functions is to be able to launch projectiles at long distances. To attain long distances, the maximum velocity at an optimum launch angle is the goal. On the other hand, the pitcher's goal is to throw a ball with more at a short distance, preferably with accuracy.

- Good **arm action** plays a crucial role in throwing for accuracy. The path the arm takes in conjunction with the timing at release determines the accuracy of the pitched ball. Observing the trebuchet's sling action gives us an idea of what circular path the pitcher's arm should take.

- **Arm action** should not be rushed, similar to how a trebuchet allows the sling to complete its path rhythmically and temporally adhering to the SHM and RF.

There are many theories as to what kind of arm action should be adopted. The one that pitchers should embrace is one that noticeably reduces acceleration and deceleration stresses. The shoulder and elbow communicate that loud and clear.

It is crucial that the arm action resembles a SPS to adhere to SHM and RF, and these two principles are essential for TIPS to be achieved.

5. Fall

- The **fall** is the first energy of motion from a posted back leg when the pitcher allows gravity to pull him forward. The fall is a motion starting in the y-direction and finishing in the x-direction. The duration of the fall lasts until the push of the back foot. The physics correlation is the '**Conservation of Energy**,' where '**Potential Energy**' (PE) is equal to **Kinetic Energy** (PE). In other words, PE is converted to KE and is depicted mathematically in scalar form as

$$mgh = \frac{1}{2}mv^2.$$

The conservation of energy is a passive relationship that does not rely on forces other than gravity. Its application in the **fall** is to prepare for the **push**. As the pitcher falls toward the target, the back leg bends to push off the rubber eventually.
Note: the pull is synonymous with the bend. There is a principle called the push-pull law in biomechanics, so the word pull is used to stay consistent with physical terminology.

<u>The Fall Using the Conservation of Energy</u>

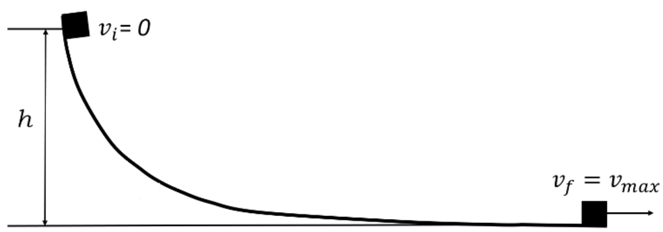
This principle states that the energy of an isolated system remains constant over time and cannot be destroyed but converted to other forms of energy. In this case, *PE* converts *to KE* as written below:

$$PE = KE \rightarrow mg\Delta h = \frac{1}{2}mv^2$$

Where,

- m is the mass of the pitcher's body
- g is the gravitational constant
- Δh is the change in the height of the pitcher's center of gravity (CG)
- v is the velocity of the pitcher's body moving toward home plate

The figure below is a classic example of illustrating the Conservation of Energy. An object of mass m is placed and held on a frictionless ramp at some height h above the ground and released.



An object at this height above the ground is said to have *PE* or stored energy. When the mass m is released from some height h, *PE* is fully converted to *KE* at $h=0$. The two key variables in the conservation of energy principle are Δh and v. The higher the value of h, the larger v_{max} is at $h=0$. Since $h_2=0$ the total height $h=h_1$. Therefore, after an algebraic manipulation of the equation above and solving for v, we get:

$$v = \sqrt{2gh}$$

Similarly, we can apply the conservation of energy to how a pitcher starts and finishes his motion in the following images. The pitcher's CG starts at h_1 and ends at h_2, where the *PE* converts into *KE*.

As mentioned earlier, the higher the value of h, the larger the v. Likewise, the straighter the post leg h_1 is, the larger the value of v. This is because the quantity of the v is only the velocity gained due to gravity acting on the pitcher's CG, pulling him down the mound.

The velocity the pitcher gains due to the conservation of energy down the mound is only to help him fall towards home plate under control and allow the post leg to bend to push off the rubber. In addition, the *KE* increases due to the impulse the pitcher created with the drive of the back leg, illustrated by the yellow dotted line. Two things happen along the way, from the beginning of the yellow dotted line to where CG ends. First, as the back leg drives the pitcher forward, the pitcher gets his arm positioned behind his head and starts to lay back (parallel to the ground) passively due to the impulse created with the drive of the back leg. Second, as the arm is lying back, all the soft tissue pre stretches to eventually unstretched in combination with muscle contraction to throw the ball, illustrated by the circular green arrow, as shown in the image across the page. Therefore, the application of impulse-momentum assists in creating more *PE,* which converts to *KE*.

6. Push

- The **push** is the second energy of motion created by the drive of the back leg. The physics relationship that coincides here is the principle of **Impulse-Momentum relationship (IMR)** represented by the equation in vector form is:

$$\boldsymbol{F}t = m\boldsymbol{v}$$

Where,

- Ft is the impulse of the pitcher's body and is the duration of time the force is exerted on the ball (ending at the fingertips exerted on the ball).
- $m\boldsymbol{v}$ is the momentum of the ball due to the impulse Ft on the ball.

The impulse-momentum is an active formulation that requires a force applied to the rubber for some time. It also indicates that the longer the **push,** the higher the velocity attained demonstrated by solving the above equation for velocity $\boldsymbol{v}$, as shown below.

$$\boldsymbol{v} = \frac{\boldsymbol{F}t}{m}$$

Where,

- m is the mass of the ball (tiny in comparison to the force on the ball)
- F is the force on the ball
- t is the duration the force F is exerted on the ball

As you plug in values for time t, where mass m is constant and very small compared to the force $\boldsymbol{F}$ applied, as t increases, so does $\boldsymbol{v}$.

<u>The Push Appling the Impulse-Momentum Principle to Prevent Injury & Increase Velocity</u>

The critical variable in the equation above is t. The main idea about this formula is that the magnitudes of $\boldsymbol{F}$ and $\boldsymbol{v}$ are dependent on the value t. Thus, if the equation is solved for $\boldsymbol{F}$, one can determine that as t gets larger, $\boldsymbol{F}$ gets smaller, as shown below.

$$\boldsymbol{F} = \frac{m\boldsymbol{v}}{t}$$

Reducing $\boldsymbol{F}$ applied on the ball starting at shoulder maximum external rotation (MER) to ball release allows for reduced stresses protecting the soft connective tissue at the joints due to violent torques created by the throwing motion, specifically at the shoulder and elbow.

All pitchers want to increase velocity. Therefore, to increase $\boldsymbol{v}$, the value t must increase as well. To clarify this notion, we can solve this equation for the $\boldsymbol{v}$ and simply plug in values, notice that as the numerator gets larger, so does $\boldsymbol{v}$ since m is small.

$$\boldsymbol{v} = \frac{\boldsymbol{F}t}{m}$$

Also, because the ball's mass m is small, it will not take a large $\boldsymbol{F}$ to overcome its inertia. However, it is imperative to note that even though the ball's mass is small, overcoming the ball's inertia too early in the throwing motion increases the magnitude of $\boldsymbol{F}$. Therefore, also increasing the stresses in the joints.

Another way to explain this concept is by writing the impulse-momentum equation signifying the variables' (m being constant) size depicts the preferred magnitudes of the variables, shown below.

$$\Huge{\boldsymbol{F}t} \small{= m} \Huge{\boldsymbol{v}}$$

So, this equation illustrates the importance that the value of t must be as large as possible to keep the magnitude of $\boldsymbol{F}$ as small as possible and make the magnitude of $\boldsymbol{v}$ as large as possible. The question that might come to mind is; if the force is kept small, how does a pitcher increase velocity? In a nutshell, a smaller $\boldsymbol{F}$ applied longer increases $\boldsymbol{v}$ of the ball than a larger $\boldsymbol{F}$ exerted at a shorter period.

Taking longer to release the ball allows the pitcher to create more momentum and store more *PE* to create more *KE* covered later in this material as he goes down the mound. Allowing the pitcher more time t to drive down the mound, increasing momentum, which in turn increases velocity.

Much research has been done to determine what movement mechanisms overload the shoulder or elbow that eventually cause injury. However, the extreme loads exerted at the shoulder and elbow cause injury, but those loads are reduced by allowing more time to load and unload the shoulder and elbow joints.

7. **Pull (bending at the hips)**

- The **pull** is the final energy of motion starting at truck forward rotation. This action begins the momentum transfer from the ground and up the kinetic chain (trunk, shoulders, arm, hand, and baseball ultimately). The physics correlation is also the impulse-momentum relationship shown in the **push** phase. Again, as mentioned in the push phase, the higher values of time produce higher velocity values. The pull phase terminates when the trunk finishes just over the front thigh. This type of finish is called trunk to thigh-throwing, armpit over the opposite knee. For short, **Trunk to Thigh-Armpit to Knee**. The advantages of finishing this way are threefold.

    - **Reduces risk of injury** – the further the arm finishes past release, the more time the arm has to slow down to decrease deceleration stresses in the shoulder and elbow.
    - **Improves accuracy** – the further the trunk rotates to full extension, the better the pitch placement.
    - **Increases leverage** – leverage is increased from the axis of rotation starting at the hips to the fingertips, rather than from the shoulder to the fingertips, to increase velocity.

The **fall** stage is the **preparation stage**, the **push** step is the **primary active force application stage**, and the **pull** step is the **final active force application stage**. It is crucial to understand all three of these stages. Also, any of these three stages must not be rushed to take advantage of longer movements (more extended or prolonged movements to increase leverage) as well as the total transfer of momentum from one link of the kinetic chain to the next.

The impulse-momentum relationship may also be used in the pull stage in the momentum generation for increasing velocity.

The Pull is the (Angular) Impulse on the Ball
The pull phase of the momentum generation cycle of the PM is in a combination of two energy systems co-occurring. The first is the soft tissue loading in front of the body, like the muscles, tendons, ligaments, and fascia, represented by the circular green arrow in the following image.

The loading of these tissues is stored energy called elastic energy (*EE*), another type of *PE*. This kind of loading is due to the pitcher applying an impulse $\boldsymbol{F_p}t$ from the push of the back leg, as shown in the following image. Again, the larger value of *t*, the better. Therefore, the longer the push, the more *EE* is stored to generate more velocity. This energy is unleashed when the front foot lands rigidly, as shown in the image below. The numbered green lines represent a link of the kinetic chain. The dotted green line illustrates that the solid green links 1 and 2 are rigid with minimal give to unload into KE fully.

What allows the tissue to unload in combination with muscle contraction is the impulse in reverse illustrated by the ground shear force *x* time $\boldsymbol{F_{grs}}t$. However, this impulse assists the trunk in creating an angular impulse producing an angular momentum and torque about the hips axis. The equation is written as shown below and in the angular equivalent to the linear impulse.

$$\boldsymbol{\tau}\Delta t = I\omega \implies \boldsymbol{F}\Delta t = m\boldsymbol{v}$$

In addition, there is an impulse from shoulder maximum external rotation (MER) to the release of the ball.

8. Hand Separation

- The **hand separation** must be equal and opposite, where the arms extend to full length in preparation for primary armload. The throwing arm's elbow should get to just above the shoulder, and the upper arm and lower arm form a 90^0 angle approximately. The glove-hand arm should stay close to the front shoulder's height.
- The **hand separation** must be as fluid and limp as possible.
- The **hand separation** should stay as close to on plane of the alignment of the feet.
- The **hand separation** should start where the hands are at the center of the body.

Hand separation is part of the timing mechanism for a consistent release point. As mentioned in the **Arm Action** section, arm action should not be rushed, similar to how a trebuchet allows the sling to complete its path rhythmically and temporally adhering to the SHM and RF. As mentioned in the arm action section, it is crucial that the arm action resembles a SPS to adhere to SHM and RF, and these two principles are essential for TIPS to be achieved.

9. Stride

- The **stride** must synchronize with the hand separation. Also, the action of the hands and stride should move symmetrically while unhurried.

- The **stride** starts as the pitcher begins to fall toward home plate. As he starts his fall, the lift leg extends to full length while staying flaccid (there should not be any muscle contraction in the stride leg). As the stride leg extends to full length, the heel of the stride foot must lead the toes. These movements ensure maximum stride length, producing maximum PE, KE, and IMP, creating more velocity.

- At the end of the **stride**, the stride foot should be within 3 inches inside of the push-off foot.

- The **stride** must not be restricted to a certain length. Let the momentum and timing of each movement throughout the motion dictate stride distance.

The stride is another part of the timing mechanism for a consistent release point and terminates when the stride foot lands.

<u>**The stride Allows for More Momentum Production**</u>

The stride allows for more momentum transfer from the drive of the back leg and the forward trunk rotation, as shown in the pitching sequence below.

10. Primary Armload

- The **primary armload** starts when the throwing arm abducts as the hands separate up to where the upper and lower arm form a 90^0 angle.

- Before primary armload, the arm must be at full extension, flaccid, and not hurried.

- The **primary armload** must stay behind the trunk to hide the ball as long as possible from the hitter.

- As mentioned in the arm action and hand separation section, the **primary armload** should be rushed to adhere to the SHM and RF.

- The **primary armload** is in preparation for the **secondary armload**.

- The **primary armload** is the timing mechanism of the **throw,** similar to the front foot of the batting swing.

- There is a slight pause of the **primary armload** before the **throw** as the front leg stabilizes.

The **primary armload** is one of the most misunderstood movements in pitching. When rushing any movement shortens leverage and does not allow the total transfer momentum through the movement.

11. Front Leg Stability

- **Front leg stability** is the front leg's rigidity when the front lands. The front leg does not hyperextend or collapse, and the front knee does not go beyond the shoelaces.

- **Front leg stability** must be attained adequately for the movements that come after are performed efficiently.

- The primary function of **front leg stability** is to decelerate the whole body at landing and arm after **follow-through** while properly transferring momentum from one kinetic link to the other to produce maximum velocity. In other words, there should not be any give forward or back of the front leg at landing.

- **Front leg stability** is the primary arm decelerator.

- **Front leg stability** is one of the most misunderstood skills in pitching.

Front leg stability is a security eccentric contraction action. Eccentric contraction is the act of muscle decelerating motion to prevent injury while improving performance. As shown in the following images, the knee does not go past the shoelaces.

Two pitchers demonstrate side by side, each in the identical position of that phase of the pitching motion. Each pair of images has implications from the first to the last set. The green line in front of the knee represents a barrier in which the pitcher's knee must stay behind. If the pitcher is successfully doing this, allow for more momentum transfer up the kinetic chain.

12. Secondary Armload

- The **secondary armload** starts at the shoulder's maximum external rotation (MER) or when the upper arm lies horizontal to the ground. The **push** phase produces this movement in conjunction with the eccentric loading of the stride leg as it lands, assisting in the forward trunk rotation. The longer the **push** stage increases the secondary armload potential, the more velocity.

- If the duration of the **secondary armload** is shortened, it increases the risk of injury.

- The **secondary armload** done correctly helps with command as long as the head, and front shoulder doesn't veer off the target before the front foot lands.

The **secondary armload** is a passive force application on the ulnar collateral ligament (UCL) due to the **push** at the rubber and forward trunk rotation. In other words, the arm does not load due to muscle contraction of the arm or shoulder. Also, the **secondary armload** must take as long as possible to reduce the acceleration and deceleration stresses in these two joints while adhering to SHM and RF.

13. Throw

- The **throw** starts as the arm internally rotates forward up to the release.
- The duration of the **throw** must take as long as possible.
- The **throw** must stay on plane with the alignment of the feet.

A strong and accurate throw is the culmination of the movements before being done correctly and not hastened.

Appling the Impulse-Momentum Principle on the Throw to Increase Velocity While Reducing the Force (Load) on the UCL

The critical variable in the equation above is t. The main idea about this formula is that the magnitudes of $\boldsymbol{F}$ and $\boldsymbol{v}$ are dependent on the value t. Thus, if the equation is solved for $\boldsymbol{F}$, one can determine that as t gets larger, $\boldsymbol{F}$ gets smaller, as shown below.

$$\boldsymbol{F} = \frac{m\boldsymbol{v}}{t}$$

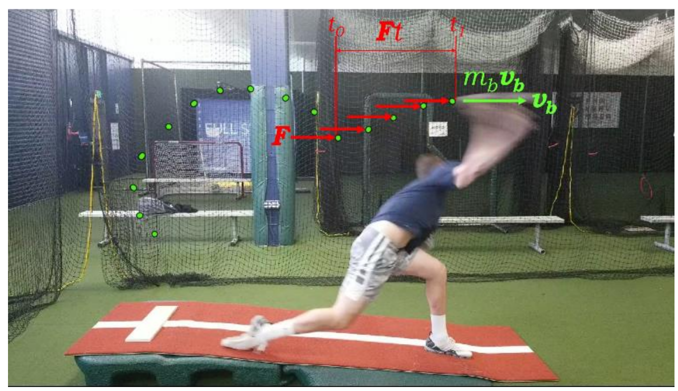
Reducing $\boldsymbol{F}$ applied on the ball starting at shoulder maximum external rotation (MER) to ball release allows for reduced stresses protecting the soft connective tissue at the joints due to violent torques created by the throwing motion, specifically at the shoulder and elbow.

All pitchers want to increase velocity. Therefore, to increase $\boldsymbol{v}$, the value t must increase as well. To clarify this notion, we can solve this equation for the $\boldsymbol{v}$ and simply plug in values, notice that as the numerator gets larger, so does $\boldsymbol{v}$ since m is small.

$$\boldsymbol{v} = \frac{\boldsymbol{F}t}{m}$$

Also, because the ball's mass m is small, it will not take a large $\boldsymbol{F}$ to overcome its inertia. However, it is imperative to note that even though the ball's mass is small, overcoming the ball's inertia too early in the throwing motion increases the magnitude of $\boldsymbol{F}$. Therefore, also increasing the stresses in the joints.

In the following image, the pitcher starts his arm path illustrated by the green dots and begins to exert an impulse $\boldsymbol{F}t$ on the ball at t_0 to t_1, inducing a change in momentum of $m_b\boldsymbol{v_b}$. If the pitcher does not continue to bend as he is doing, it decreases the time t increasing $\boldsymbol{F}$ and decreases $\boldsymbol{v_b}$.



Another way to explain this concept is by writing the impulse-momentum equation signifying the variables' (m being constant) size depicts the preferred magnitudes of the variables, shown below.

$$\boldsymbol{F}t = m\boldsymbol{v}$$

So, this equation illustrates the importance that the value of t must be as large as possible to keep the magnitude of $\boldsymbol{F}$ as small as possible and make the magnitude of $\boldsymbol{v}$ as large as possible. The question that might come to mind is; if the force is kept small, how does a pitcher increase velocity? In a nutshell, a smaller ***F*** applied longer increases ***v*** of the ball than a larger ***F*** exerted at a shorter period.

Taking longer to release the ball allows the pitcher to create more momentum and store more *PE* to create more *KE* covered later in this material as he goes down the mound. Allowing the pitcher more time *t* to drive down the mound, increasing momentum, which in turn increases velocity.

Much research has been done to determine what movement mechanisms overload the shoulder or elbow that eventually cause injury. However, the extreme loads exerted at the shoulder and elbow cause injury, but those loads are reduced by allowing more time to load and unload the shoulder and elbow joints.

14. Release

- The **release** is where the ball starts to come off the fingertips and is at maximum velocity.
- The **release** of the ball should be somewhere in front of the front foot.

A consistent release is attained when the trunk and arm move as one lever, as shown in the image across the page, increasing leverage from the hips to the fingertips. In other words, prevent as much hinging of the trunk and arm at the shoulder as shown in the images below.

15. Follow-Through

- The **follow-through** is one of the least adequately addressed skills in pitching.
- A proper **follow-through** is where the arm is given more time to slow down to reduce deceleration stresses in the shoulder and elbow.
- A proper **follow-through** allows the larger muscles the assist in the deceleration of the arm.
- An adequate **follow-through** allows the arm to stay on the target longer, improving command.

The **follow-through** and the **pull** occur simultaneously since the pitcher pulls until the trunk is over the front thigh and the throwing arm's armpit finishes over the opposite knee (trunk to thigh armpit to knee for short), as shown below.

A poor finish is when the arm is in the position shown in the following image. When the pitcher finishes in this way, the shoulder and arm have to do most of the work, overloading the shoulder and elbow joints.

16. **Efficiency of movement**

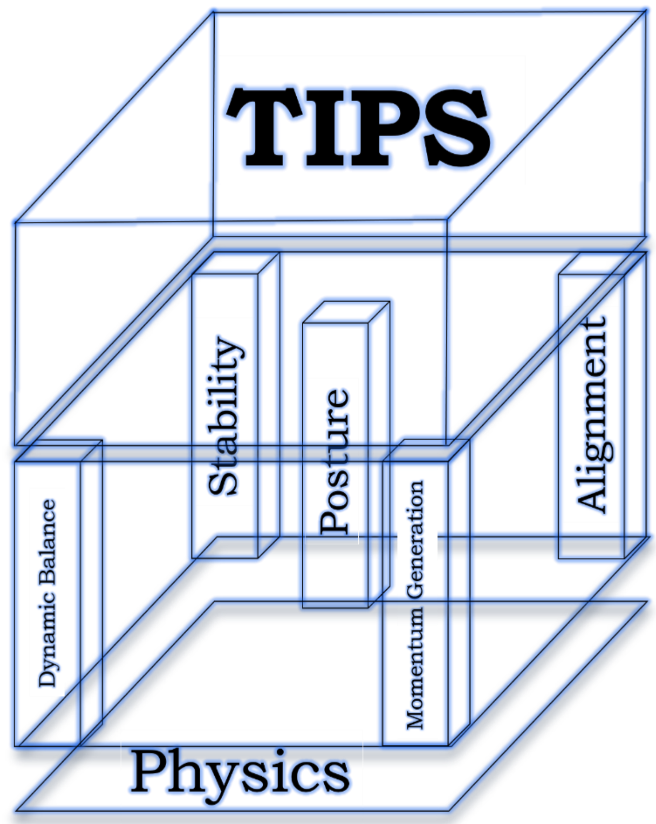
- **The Sequential summation of movement** is biomechanics's version of physics's conservation of (angular) momentum.
- **The synchronicity of movement** is a harmonious marriage of movement of the lower and upper body.
- **The symmetry of movement** is the evenness of movement of the right and left sides of the body as the pitcher moves toward HP.
- **The Rhythmicity of movement** is the length of smooth movement that is not hurried.
- **The temporality of movement** is a specific tempo or pace of the movement.

A clarification of how rhythm and tempo are used in this system; often used to mean the same thing. A pitcher's movements must be as long as possible to produce the proper tempo. It should make sense that if the movements are shortened, the tempo must speed up, which contradicts the theory of SHM and RF.

<u>The Five Pillars of TIPS Adhering to Physics laws</u>

Although physics is a quantitative discipline requiring number crunching to come to a solution, it is utilized conceptually qualitatively in this literature to govern pitching movement. These 16 skills covered in this literature were developed with TIPS in mind while adhering to physics laws, including SHM and RF. In addition, the foundational structure of **TIPS** is the **five pillars** in their proper order with **physics laws** as the foundation**,** as shown below.

1. **Posture**
2. **Alignment**
3. **Maximum (angular) momentum generation**
4. **Dynamic balance**
5. **Stability**



Good **posture** allows for pillars **2** through **5** to occur effectively. **Alignment** allows for improved accuracy and velocity while permitting **maximum (angular) momentum generation** in line with the target. **Dynamic balance** must be maintained, allowing the CG to stay central to the pitcher's **BoS** from the start to the ball's release. **Stability** is crucial for allowing **maximum (angular) momentum generation** of the push of the back leg to the landing of the stride leg. These **five pillars** assist in the analysis of pitching mechanics and can easily be detected on video.

Conclusion

As covered in this literature, the pitcher's movements have different connotations.

- Movements due to muscular contraction and relaxation
- Are the movements linear or angular
- Movements due to a force or torque (moment) causing the moton
- Are the movements efficient or inefficient
- Are the movements long or short
- Should the movements be long, short, or a mixture of both
- How fast or slow are the movements
- Should the movements be fast, slow, or a mixture of both

Physics has the answer to all the statements and questions above. Physics is rich with insight improving performance (accuracy & velocity) while preventing injury if we use physics models similar movements to how a pitcher moves, such as a trebuchet and a SPS that obey SHM.