Nibbling on Newton:

A Physics Primer

Before entering the training world I had no background in physics and thought it should best be left to the really scary smart people with disheveled hair and far-away stares. Little did I realize how critical an understanding of this cool science was required, not just to be a good fitness pro, but also to be a more effective exerciser.

In this article I will touch upon some physics concepts—presented in a user-friendly way—that will help you understand how we are constantly interacting with the laws of nature, why we move the way that we do, and how to make your movements more efficient and effective.

Part 1 will get you grounded in two fundamental concepts, ***Base of Support*** and ***Center of Gravity***. They are the essential physical properties of all objects, both animate or inanimate, and will give you context for learning how to manipulate them to make your workouts more challenging and beneficial.

Part 2 will delve into Sir Isaac Newton's ***3 Laws of Motion***, which dictate how movement works. You may have heard of at least one of the laws before (perhaps we'll jog distant memories of high school physics) but you've definitely experienced their effects every day. Not only will it become clear why getting up from the couch requires you to push down into the ground but you will learn how to get stronger, more well-coordinated, and better balanced in the gym by taking full advantage of these invisible, yet indispensible laws.

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Part 1:
Base of Support,
Center of Gravity

Base of Support (BOS)

Definition: The points of contact with a supporting surface and all of the area within those points. For example, if you are standing comfortably like the beach goer in photo 1 your BOS would be the area under your feet and within them.

BOS is direction-dependent, meaning that you are only stable in the direction in which you maintain a large base. In photo 2, you can see that the man displaying an exemplary horse stance has his feet spread very wide, relative to the person in photo 1. This means that the martial artist will be more stable from side to side and it would take a much larger force from left or right to knock him over.

Photo 1: In quiet stance, as this person is demonstrating on the beach, the BOS is the area under and within the feet, as demarcated by the yellow line.

Photo 2: This gentleman's horse stance creates a very stable base from side-to-side but makes him susceptible to losing his balance if pushed from the front or back.

Even though the fierce warrior has a much wider BOS than the beach goer he could get knocked over relatively easily if someone were to stand in front of him and push him in the chest. Why? Because his base from front-to-back is only as large as the length of his feet.

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Similarly, the woman in photo 3 has established quite a long BOS from front-to-back so she will remain standing if pushed in her chest. But, because her feet are narrow from side-to-side, she can easily be knocked over if someone were to gently push into the side of her shoulder.

The solution? The football player in photo 4 has created a very stable BOS by placing a hand on the ground, increasing the area supporting him, so he will be able to withstand higher levels of force from any direction before getting knocked over.

Photo 3: This woman is positioned for a split squat with a large, stable BOS from front to back but this alignment makes her susceptible to losing her balance if pushed from the side.

Photo 4: This football player has created a very stable BOS from front-to-back AND side-to-side.

Keep in mind that, although the examples in the photos refer primarily to the feet as the points of contact with the ground, one's BOS can also be other body parts. For instance, if you were hanging on a bar about to do a pullup your hands and the area between them (on the bar) would be the BOS. Likewise, if you were in a plank position about to do a pushup your BOS would be the area under and between both hands and feet.

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Center of Gravity (COG)

Definition: The point in the body or an object where all the mass is equally balanced, also referred to as the center of the total body mass (1).

In the standing human, the COG is usually located around the belly button. It tends to be a little lower for women, who usually carry more mass in the lower body, whereas it tends to be higher in men due to their greater upper body mass. In infants, the COG is also higher because of the larger head size in relation to the rest of the body's weight.

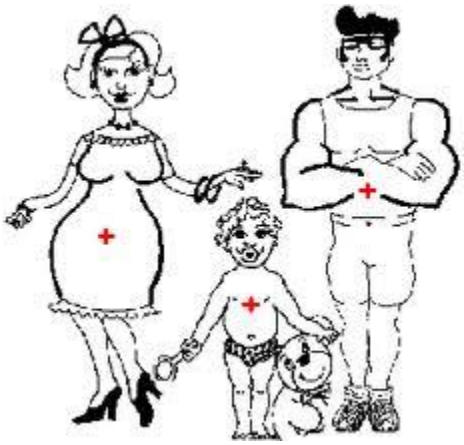

Photo 5: The COG on an average-sized adult is slightly below the belly button but it will shift in the direction in which a person carries a greater amount of mass. The red + indicates the COG in these 3 different bodies.

The location of the COG can change if:

1. You move or lift a body part away from the "home" position (standing still with arms down by the sides). ***The COG will shift in the direction of the displaced limb or body part.***

   For example, little Stevie uses his right arm to reach to the top shelf in front of him for that irresistible, cuddly teddy bear. That movement will cause his COG to shift up, to the right, and in front of him. Be careful, Stevie!

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Photo 6: This looks like a rather simple reach but Stevie's has to stabilize himself while his COG shifts up, forward, and to the right.

2. You hold a weight. ***The COG will shift in the direction of the load***.

   For example, If you pick up a bottle of detergent with your left hand and held it by your side then your COG will shift down and to the left. Likewise, if you hold a weight over your head with your right hand your COG will shift up and to the right.

Now that you have an idea about what BOS and COG are, you may be asking yourself:

What do these concepts have to do with my workouts?

You may exercise to get stronger, be more agile, function better in your life, stave off the effects of aging or for any number of other reasons. Regardless of your motives, understanding the basic physical properties of objects can help enhance your workouts.

By knowing that picking up a weight will shift your COG in its direction or widening your BOS will make you less wobbly on split squats, you will be more productive and safe during your workouts.

Below are some examples of exercise goals that will be made more effective with your new knowledge.

Getting stronger

Increasing your BOS will make you more stable, giving you a sturdier foundation from which you can lift more weight.

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For example, if you are doing standing shoulder press and you usually use a narrow stance, try widening it from side to side and front to back (staggered stance) to give you a larger BOS.

Likewise, doing a deadlift (bowing while holding a weight in front of your legs) will cause your COG to shift forward so you will need to counterbalance that force by shifting your weight backward to maintain good stability throughout the lift. So, stick your butt to the back wall for a stronger, more sturdy lift.

Improving balance

Being well-balanced—what is technically called *equilibrium*—occurs when the COG remains directly over your BOS.

If you "lose" your balance then you've just experienced the point at which your COG moves beyond your BOS.

Photo 7: Stan is going to fall because his COG (blue circle) has moved outside of his BOS (yellow circle). He has lost his equilibrium.

If you are trying to improve your capacity to remain balanced even when you are in situations that challenge your stability, there are ways to focus your gym efforts to work on this.

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Some general ideas to challenge your equilibrium:

- Hold loads farther away from your body—forwards, backwards, and to either side—to shift your COG to the limits of your BOS
- Reduce your BOS (i.e. bring both feet together, stand on 1 foot).

Some specific examples of balance tweaks to common exercises that will challenge your ability to maintain equilibrium:

- Stand on 1 leg (this alone may be enough for some people) while moving your arms and other leg around you,
- Do conventional exercises holding 1 weight instead of 2 (i.e. chest press, squats) to load you only on one side at a time
- Lunge with arms overhead instead of down by your sides
- Do exercises on the cable column to change the line of pull—free weights want to drop straight down to the ground because of gravity's pull, whereas cables want to retract back to their home position along the cable column, creating unique horizontal and diagonal pulling forces.

With all of the above examples you will be forced to recruit all of your stabilizing postural muscles, which tend to get quieted down when you stick to machines or exercises in highly stable positions.

Note: You may be tempted to train your balance by using wobbly boards, squishy surfaces, bouncy balls, and other colorful gym toys. While those implements definitely alter your BOS and will challenge your ability to control your COG, just keep in mind how you move in real life. Typically don't have to contend with moving surfaces underneath you.

If you do happen to lose your balance and fall it is likely because you mistimed or misplaced your foot relative to where it should have been to accept your shifting COG during walking. And even if ice were the culprit those gym toys don't replicate slippery. So, stick mainly to solid surface training and throw in the toys for an occasional change of sensory stimulation.

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Functional Training

In the real-world we use our bodies to lift, reach, grab, carry, and transport objects and ourselves, causing shifts in our COG and BOS. In order to do those activities successfully it would be helpful to implement those same conditions into your training.

For example, when we lift bags overhead or pull open doors we have to do so with our feet as our BOS. Therefore, sitting on machines in the gym while pressing or pulling creates a more stable base (butt and feet on floor) than we really use when outside of the gym. The biomechanical environment of a machine is an artificial one that does not transfer much to real-world situations.

Try doing the bulk of your lifting in positions that we encounter in life: ***standing, squatting, kneeling***. Reserve seated and lying positions for the hours you spend at your desk or in bed.

Senior Fitness

Some of the effects of aging directly influence one's ability to remain in control of the COG and BOS.

1. Decreased height (hunched over posture), reduced muscle mass in the upper body, and increased body fat storage in the lower body often lowers the COG in seniors.
2. Changes in the vestibular system and the side effects of prescription medications can make for more movement in the COG even while in quiet stance.
3. Decreased visual acuity makes it harder to inspect one's surroundings for steps, curbs, and obstacles, increasing the risk of falling
4. A slower, shuffling gait pattern also increases the risk of falls
5. Aging reduces the number and sensitivity of the sensory receptors on the bottom of the feet, which are used to help determine one's body positioning in space (yet another reason why older people are at greater risk of falling)

(I wrote an article which details the changes of aging and what you can do to increase your strength, power, and balance. Click **HERE** to read it.)

For those in need, canes and walkers help increase stability by making the BOS larger (by increasing contact points with the ground).

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Photo 8: Larry's BOS grew substantially with the aid of a walker, creating 6 points of contact with the ground.

If you are a senior exerciser either new to the gym or contending with compromised balance start out with exercises that are performed in stable positions: lying, seated, or standing with a hand on a stable surface (i.e. cane, walker, wall).

As you get stronger and more familiar with the movements, challenge yourself by slowly removing those layers of stability (reducing BOS). For instance, lower the weight on the shoulder press and do it without holding on to the bench.

Also, practice movements that tend to be challenging to stability, such as those found transitioning from one position to another: sitting to standing, kneeling to standing, walking. Those are moments when the COG can teeter close to the edges of the BOS, creating instability and the potential for falls.

Hopefully, you have now come to appreciate how the body orients you—often without conscious awareness—and keeps you balanced, regardless of the demands you place on it. Now it's time to turn to Newton, who will guide us to a better appreciation for how the laws of motion govern our movements.

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Part 2:
Newton's Three Laws of Motion

Before delving into the specific laws it is critical to define and understand the role of that all-important force, gravity.

Gravity

Definition: A constant downward force that acts on all objects at a rate of 9.8m/s^2.

Gravity is the reason why your keys fall straight down when dropped and a punted football eventually lowers to the earth. This constant force also results in a downward line of pull of our dumbbells and other free weights in the gym.

Keep gravity in the back of your mind when you read about Newton's laws because it is always acting on us and influences how we are able to manipulate objects and ourselves in space.

Newton's First Law of Motion

Definition: An object at rest (or in motion) will remain at rest (or in motion) unless acted upon by an outside force great enough to change its state.

This law is also referred to as the ***law of inertia***.

There are two types of inertia: ***static*** and ***dynamic***. When an object is at rest it has static inertia. When an object is moving it has dynamic inertia.

Real-life example: Your sofa is resting peacefully against the wall—it contains static inertia—and you have no reason to pay attention to it until you accidentally kick your favorite toy car underneath it. Now, you must lift the heavy object to recover that gift from aunt Suzy by applying a force greater than the one keeping the couch still. Essentially, you must change the inertial state of the sofa (from static to dynamic) to raise it off the floor, delicately sweep the toy out from underneath, and return the sofa back to its resting state on the ground.

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Photo 9: Emma was strong enough to overcome the sofa's static inertia and pushed it in order to retrieve her toy car. Hey, a girl's gotta do what a girl's gotta do.

Gym example: You are about to squat with 20lb dumbbells in your hands. In honor of Newton, I've broken down the major inertial phases into separate, smaller chunks.

1. Just standing still (static inertia) requires you to resist the downward pull of gravity and the 40 extra pounds on top of your own body weight.
2. You begin the descent and, assisted by gravity, have overcome static inertia and have now generated dynamic inertia—this part feels pretty easy.
3. When you near the bottom of a squat you must stop your descent, which requires a change from dynamic to static inertia, in addition to resisting gravity's desire to keep lowering you towards the ground. Now, you have stopped at your lowest point.
4. In order to stand back up, you must make the transition from static to dynamic inertia while fighting against gravity and its downward pull on the weight throughout your ascent.
5. Once you get to the top and have finished the rep—shifted from dynamic to static inertia—you can thank gravity for the assist because it helped you come to a stop at the top.

Photo 10: The picture on the right shows Jack at the hardest part of the squat because he's contending with gravity, the weight, and must overcome static inertia to stand up.

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Pay attention to the inertial transitions in your workouts because those instances often require the most effort to implement effectively. The best athletes can start, stop, and change directions with excellent precision and minimal wasted energy.

Newton's Second Law of Motion

Definition: The force applied to an object (mass) produces a proportional acceleration.

Another way to say this is that if an object is accelerating then there must be a force acting on it.

The greater the mass of the object, the greater the amount of force needed to accelerate it. For example, if you wanted to move the big couch to retrieve your car, you'll need to apply a lot more force than if you wanted to lift a small chair. Likewise, you can accelerate the lighter object much faster because it has less mass. The equation that sums up this law is:

Force=mass x acceleration (F=ma)

In the gym, most people tend to think of increasing strength (force production) solely by raising the weight (mass). However, by using Newton's formula you can also increase force by increasing the acceleration. Take the bench press as an example:

You complete one rep with 100 pounds in 2 seconds. You have two options to increase your force output, according to **F=ma**. 1) Increase the weight or 2) Increase the speed. So, you could load up another 20 pounds on the bar and take the same 2 seconds to finish the lift or you could keep the 100 pounds but complete the rep in 1 second. Either way you come out with a net improvement in force production.

Photo 11: Either load up or speed up to increase your force production.

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It's important to mix up your methods so that you stimulate different muscle fiber types, energy systems, and neurological adaptations. Some days train with an emphasis on moving lighter weights more quickly while other days focus on lifting heavier weights.

Newton's Third Law of Motion

Definition: For every action there is an equal and opposite reaction.

You've probably heard something like this before and this happens to be my favorite of the 3 laws. How does it work in real life? Well, how do you lift the couch to get that toy car? You apply an active force into the ground with your legs and the ground pushes back up into you (reactive force), allowing you to summate that force into useful sofa lifting strength.

Likewise, in order to get back up from the lowest part of a pushup (elbows bent), you apply active force into the ground with your arms and the ground pushes back an equal amount of reactive force that results in you lifting up (elbows straight).

You are a result of the forces you apply

Another way to say this is that you move one way because you've applied force in the opposing direction.

This one simple concept dramatically changed the way I lifted weights and has turned on a light switch for my clients as well.

You know those front lunges you've been doing? Well, instead of thinking that you lunge forward and then pick up your front foot to return to your original position, think of it this way: Once you are at your lowest point in the lunge you must apply force down and forward in order for the ground's reactive forces to push you up and back to your desired end position.

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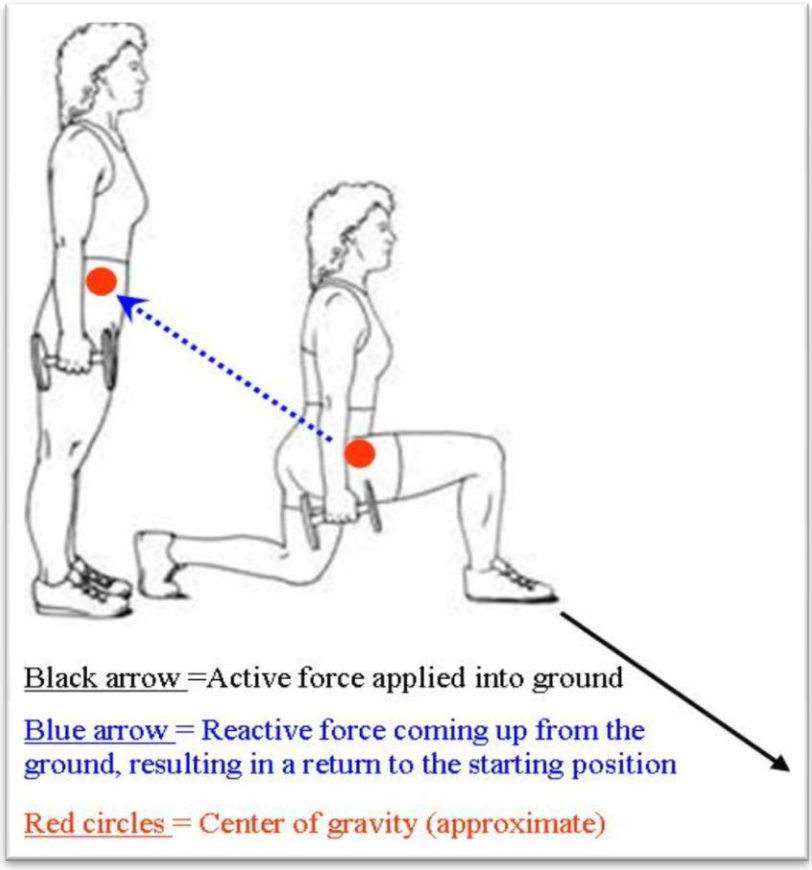

Consider what position you want to end up in and then apply force in precisely the opposite direction.

Summary

I hope that this physics primer has helped lead you to a better understanding of your own movements and how you can apply these principles to your exercises. The better and more precisely you can alter the variables of COG, BOS, acceleration, force production, active and reactive forces, and inertia the stronger, more well-balanced, and efficient you will become.

Keep on Movin'

-CA

(1) Shumway-Cook, A., & Woollacott, M.H. (2007). *Motor Control: Translating Research into Clinical Practice* (3rd ed.). Philadelphia, PA: Lippincott Williams & Wilkins.

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