Mass-Spring System shows a Natural Kinematic Sequence

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First a brief review of the kinematic sequence during the golf swing. Refer to the graph in Figure 1. This is the kinematic sequence of a world class golfer. To remind you, the red curve is the rotation speed of the pelvis, the green is the thorax (upper body), the blue curve is the lead upper arm and the brown curve is the club shaft. During the downswing and before impact the pelvis accelerates then decelerates, as does the thorax, the arm and the club. Notice that each peak occurs after the previous one (shifted to the right in the graph) and is faster (taller) than the previous one. Research in biomechanics has shown this to be an efficient method of transmitting energy from the large core segments (pelvis and thorax) to the smaller distal segments (arms and club). The muscles across each joint that is involved in the sequence transmit the energy from the previous segment and add energy of their own with the result being an increase in the speed of the next segment.

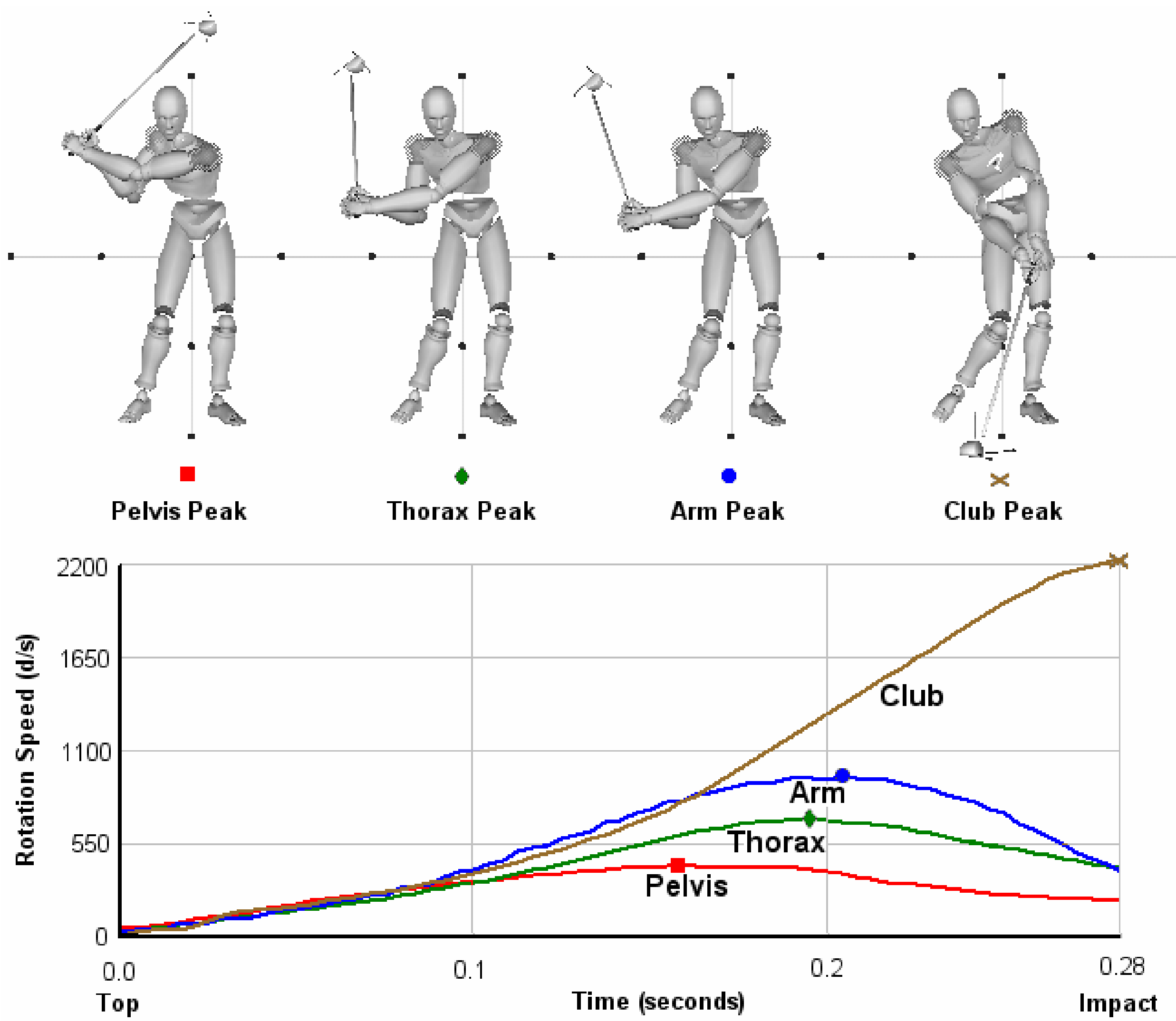

Figure 1.

Surprisingly this same profile can be seen when we look at a simple mass-spring system, also known as a coupled harmonic oscillator. Imagine three blocks laying on an “air-hockey” table; a heavy one, say 5 kg (about 10 lbs); a medium one, say 3 kg; and a small one, say 1 kg. The heavy one is attached to the wall with a spring and each block is attached to the other with a spring (Figure 2).

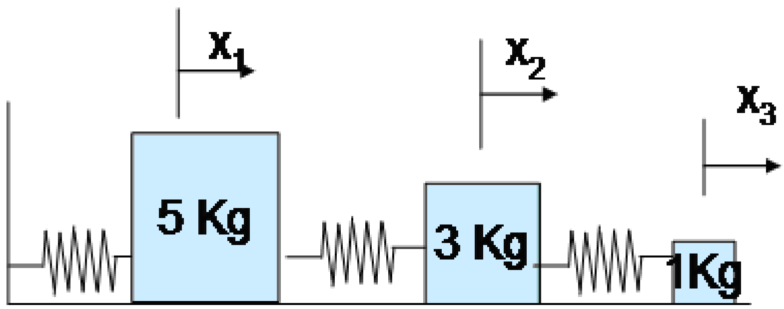

Figure 2.

For this example all the springs have the same stiffness and we can ignore the effects of friction and gravity. If you compress each spring, say 0.5m and let them all go at the same time you get the velocity graph shown in Figure 3.

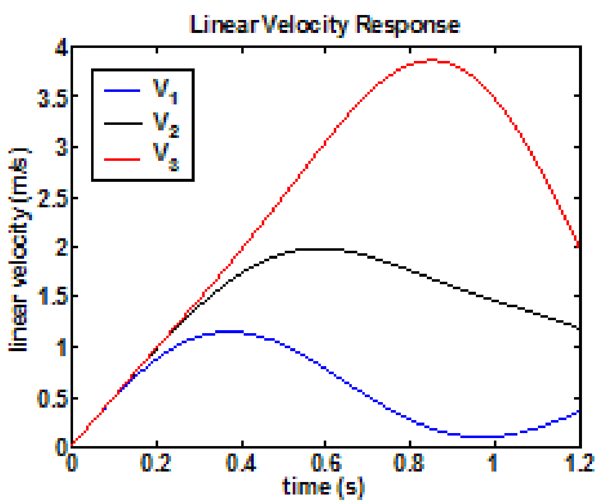

Figure 3.

Notice that the blue curve is the velocity for the heavy block (V_1), black for the medium one (V_2) and red for the light one (V_3). This looks very similar to the forward swing section of the kinematic sequence graph of an expert golfer (see Figure 1), just with one less segment and different periods and speeds. This mass-spring model is known as coupled harmonic oscillator. This increasing velocity profile only occurs though if the blocks decrease in weight. This makes intuitive sense since it is easier to speed up a smaller mass than a larger one. In biomechanics terminology this is called an open kinetic chain. If the masses are reversed as in Figure 4 then we get a very different velocity profile.

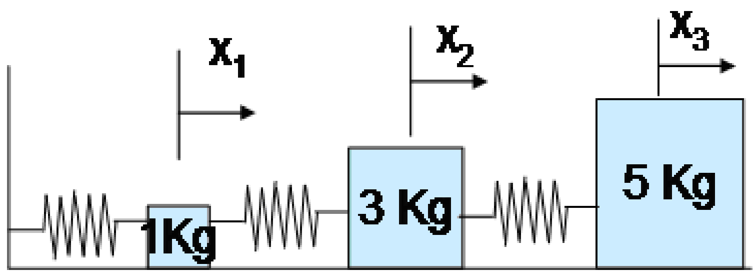

Figure 4

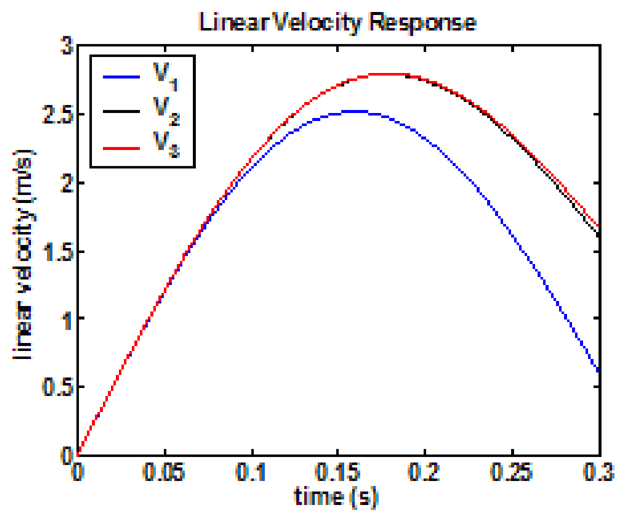

Figure 5

The new velocity profile is shown in Figure 5. V_1 is now the small block, V_2 the medium block and V_3 the heavy block. It seems in this case the small block is only able to increase the speed of the medium block a little and the medium block is not able to increase the speed of the large block at all!

If instead the blocks were disks of decreasing diameter, (Figure 6), similar to the model proposed by Cochran and Stobbs in their book "The Search for the Perfect Swing" then the curves will be similar to Figure 3. This is because the equations of motion end up the same for the linear model as the rotational model except that mass is replaced by moment of inertia, linear speed with rotational speed and linear spring stiffness with torsional spring stiffness. Now it looks more like a golf swing!

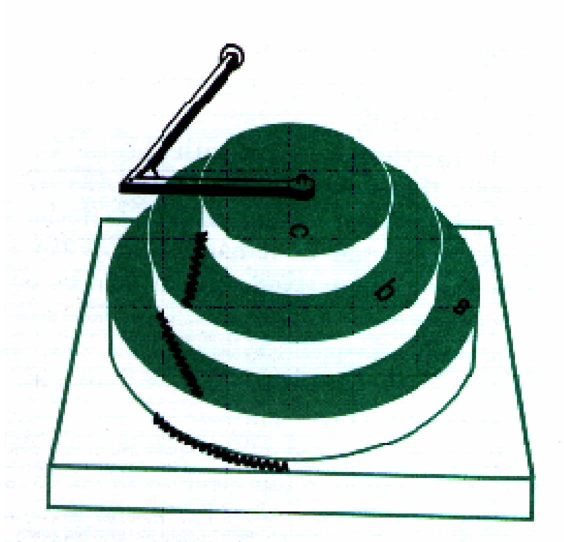

Figure 6

So what does this suggest about how we swing a golf club? Perhaps the expert golfers have learned how to optimize this natural mass-spring motion that is inherent in our musculoskeletal system. The muscles act as the springs and the segments are the masses. Notice how the arms and the club are much smaller and lighter that the pelvis and thorax. On the other hand, perhaps the novice golfer inhibits this efficient natural action by forcing the swing, turning the muscles on and off at the wrong times, resulting in a disorganized kinematic sequence.

The mass-spring mathematical model used in this discussion was developed by Young-Kwan Kim (PhD), currently a post-doc in biomechanics at Arizona State University. He is researching the kinematic sequence in baseball batting which is very similar to that of golf.

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