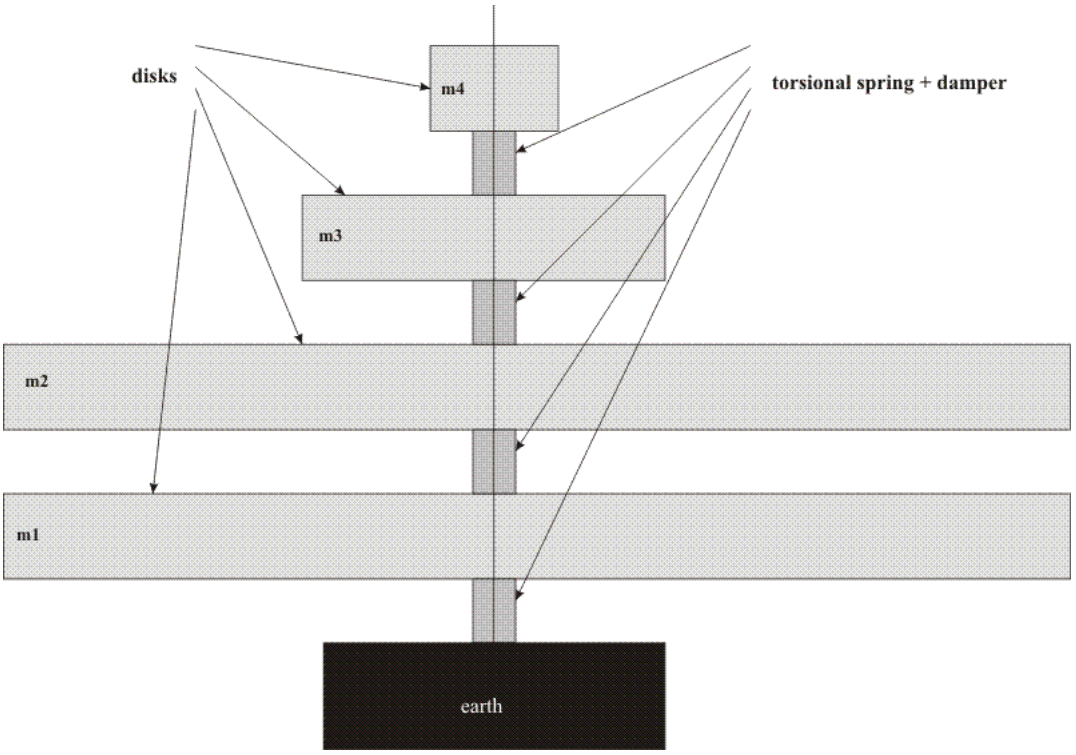
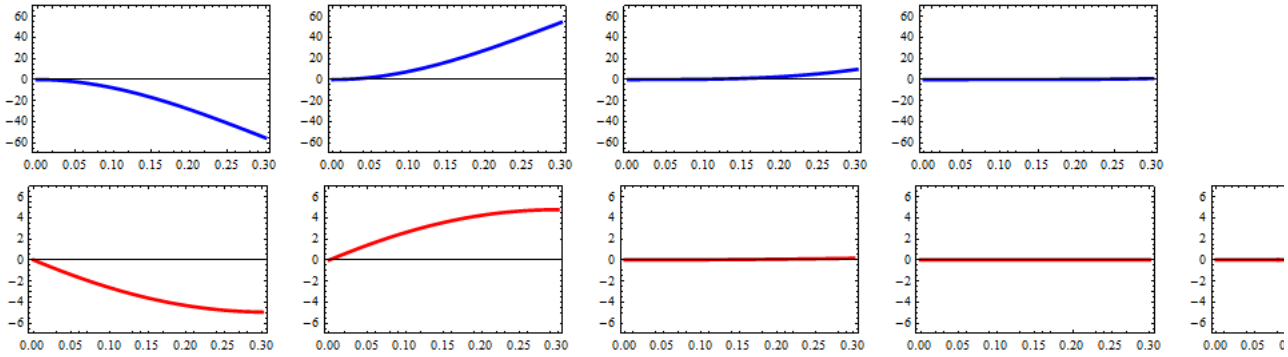
Analysis of conservation of angular momentum using model including ground reaction force



The model used for our analysis consists of 4 disks which have a common axis. Between disks and between disk1 and earth there are torsional springs and dampers. Also between disks one can have torques applied, but none between disk1 and earth, hence we have only internal torques operating in the system. The only possible external force acting on the system can come form the spring and damper connecting the system via m1 to earth. This is only a very crude generic model of a golfer only intended to show the interaction of internal forces with earth and the ensuing behavior of angular displacements and angular momenta of the disks. The force, associated with the torsional spring/damper between mass1 and earth, represents the ground reaction force acting on a golfer during the swing.

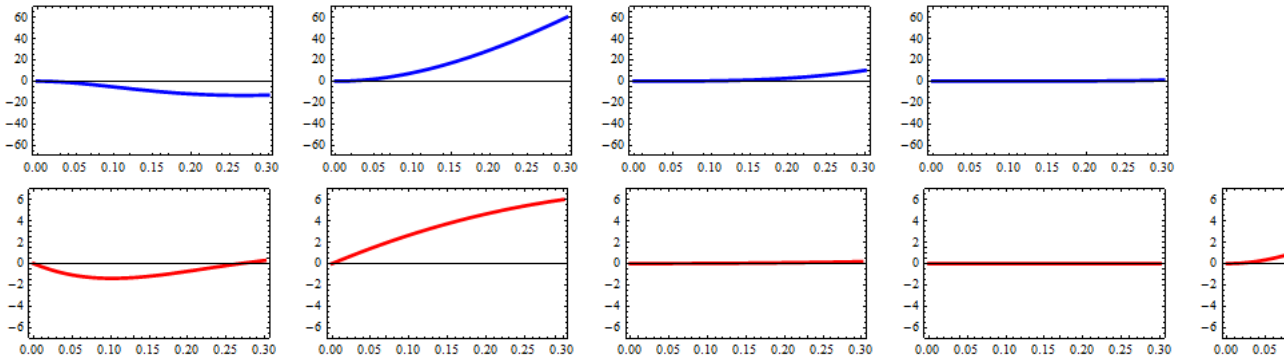
With this mathematical model we can analyze what happens when torques are applied between the various disks. Again one could fancy the torque between m4 and m3 as being the wrist torque, between m3 and m2 as some shoulder torque and between m2 and m1 as representing a hip torque. One can ask questions such as what happens, when I activate one of these torques, with the angular displacements and the various angular momenta? What would happen when we imagine the golfer to be out in space or on a very slippery surface?

We will do 6 experiments. There are three internal torques successively applied and for each torque we have also run for the situation as if the golfer is just floating above the earth, ie. no damper/spring between m4 and the earth. The 'blue' curves represent relative angular displacement (deg). The 'red' curves represent angular momenta (kg m^2 / sec). The horizontal coordinates represent time in secs. From the left to the right curves correspond to disks 1, 2 3, and 4. The solitary curve sticking out on the right represents in each case the sum of the angular momentum of the 4 disks, hence the total angular momentum of the system.



Experiment 1a - Torque applied between m1 and m2. No connection between m1 and ground.

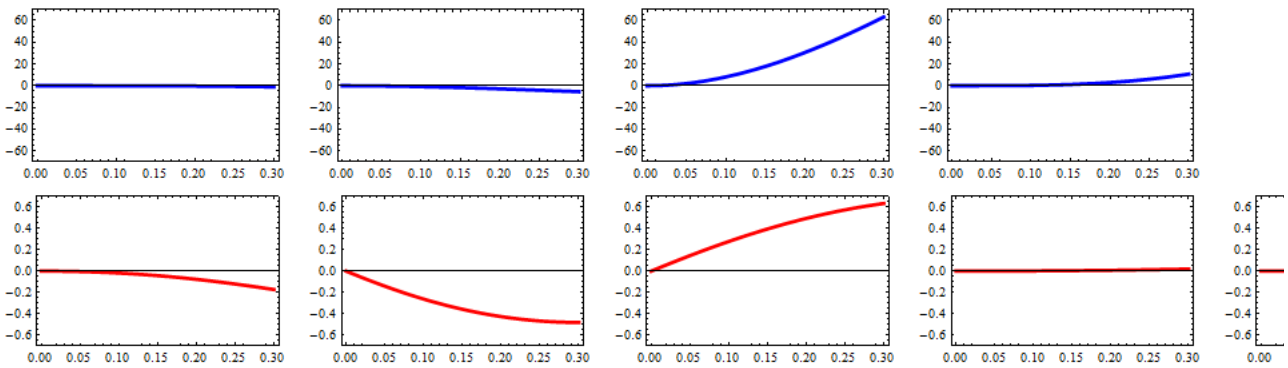
Notice that the internal torque between m1 and m2 doesn't increase the total angular momentum, it remains zero.



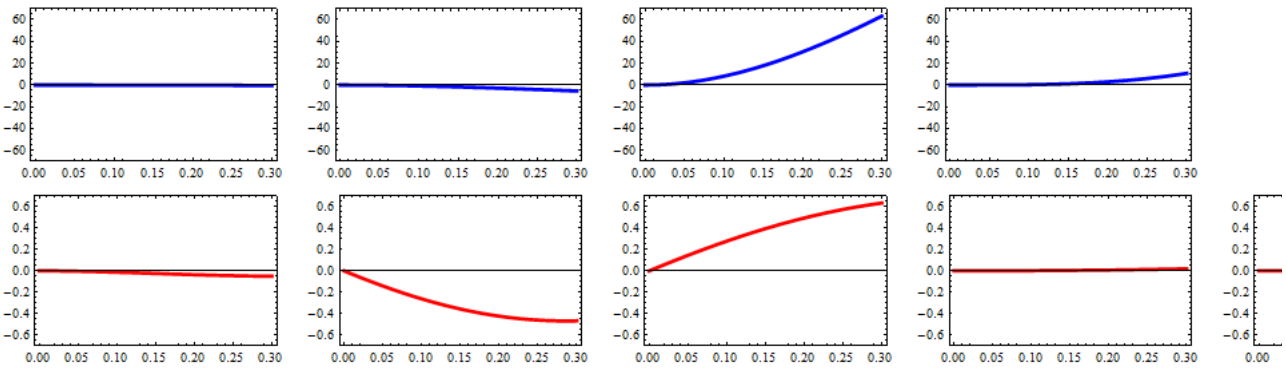
Experiment 1b - Torque applied between m1 and m2.

From experiment 1a and 1b it is immediately clear that the internal torque between m1 and m2 provokes, via damper and spring, a ground reaction force, which now, acting as an external force on the system, can increase the angular momentum of the system. For this experiment the total angular momentum is almost equal to the angular momentum of disk2.

Let's repeat the same experiments for the two other torques between disks, situated more distal re the ground. Lets do first the experiment with the torque applied between m2 and m3.

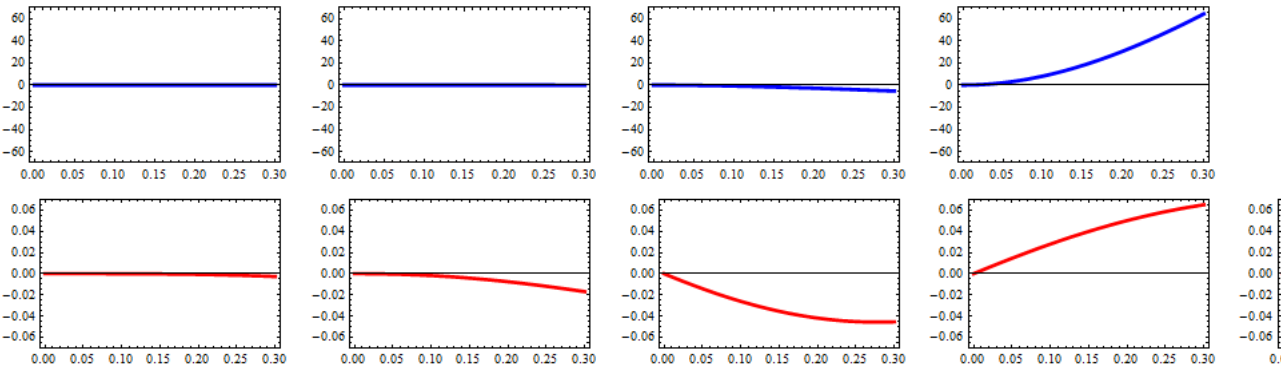


Experiment 2a - Torque between m2 and m3. No connection between m1 and ground.

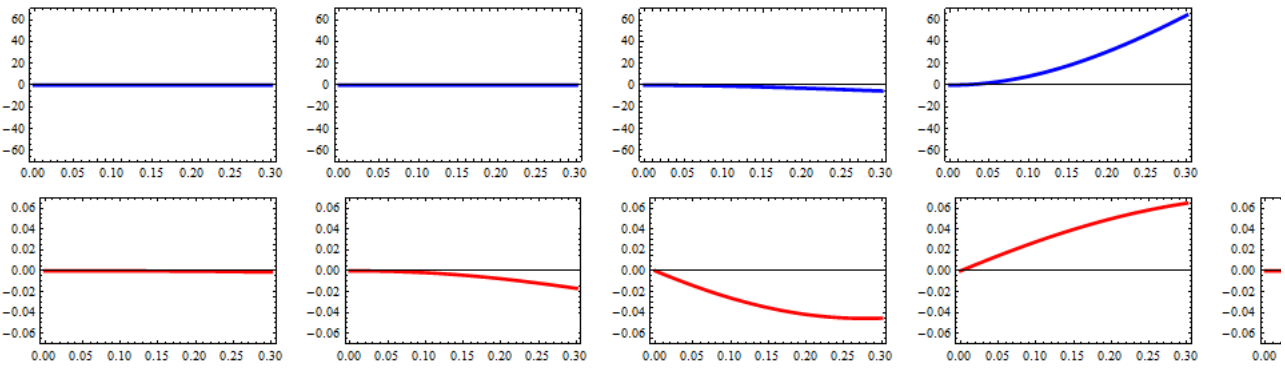


Experiment 2b - Torque between m2 and m3.

Notice an interesting change from experiments 1a and 1b. This time the angular momentum generated by the torque acting between m2 and m3 does contribute much less to the overall angular momentum. The angular momenta of mass m2 and m3 have opposing signs and virtually cancel each other. So it will be interesting what will happen if we apply a torque between disk3 and disk4 4 the most distal elements.



Experiment 3a - Torque between m3 and m4. No connection between m1 and ground.



Experiment 4a - Torque between m3 and m4.

The trend definitely continues as is there is now no noticeable increase in total angular momentum due to the torque between disks 3 and 4. In other words a golfer with spikes on grass and a golfer barefooted on a very slippery surface, when torquing his wrist, produces virtualy the same effect on the system.
Hence in our last experiments the internal torque applied betweenm m3 and m4 does not increase the angular momentum of the system, its contribution is negligible.

Concluding remarks

The overall conclusion of our six experiments imposes itself now very clearly. Let's use the image of a pyramid. At the bottom internal torque directly increases the total angular momentum. Somewhere halfway up torque still contributes partially and at the top it does not contribute anymore to the total angular momentum of the system.

The image which imposes itself rather naturely and intuitively is that the lower (proximal) body parts of the golfer are injecting net angular momentum into the golfer/club ensemble and that towards the more distal parts of the golfer the emphasis is increasingly more on redistribution of available angular momentum injected into the system from the bottom up.

Also it should be clear the funny way the ground force comes into the picture as an external force. For every internal torque, especially proximal torque, an associated reaction force is generated, between golfer and ground. Thereafter this ground reaction force acts on the golfer as an external force and it is only this external force which can generate any net positive angular momentum.

Therefore internal torque can only generate net positive angular momentum in a golfer/club ensemble to the extend that they are capable of generating some external reaction ground force. Significant for the hips but negligible for the wrists.

The kinetic golf swing sequence can now be viewed rather accurately to be initially mainly generating angular momentum but rapidly changing the process to primarily redistributing the generated and available angular momentum towards the distal end point (clubhead).

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