KIN 335 - Biomechanics

LAB: Ground Reaction Forces - Linear Kinetics

Reading Assignment: 1) Luhtanen, P. and Komi, P.V. (1978). Segmental contribution to forces in vertical jump. *European Journal of Applied Physiology*, **38** (3): 181-188. 2) Harman, E.A., Rosenstein, M.T., Frykman, P.N., & Rosenstein, R.M. (1990). The effects of arms and countermovement on vertical jumping. *Medicine and Science in Sports and Exercise*, **22** (6), 825-833.

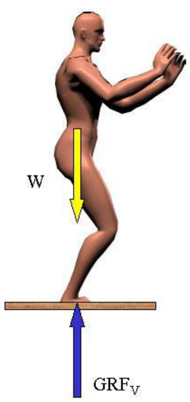
Introduction: Most of our movements ultimately rely upon our interaction with the ground. We are constantly pushing against the ground both vertically and horizontally as we initiate and modify movements of the total body and body segments. Consider just a few examples of movements, both simple and complex, that depend upon our ability to push against the solid base of the earth: walking, running, reaching up in a cupboard for a glass, a push up exercise, raising your hand to ask a question, and jumping (the focus of today's exercise). Because of the importance of our interactions with the ground in the generation and modulation of our movements, the ground reaction force (GRF) could arguably be considered the most important external force acting on the body. What is important to keep in mind is that the ground reaction force is largely under our control via coordinated muscle actions. By producing a certain combination of muscle actions, we ultimately push against the ground which pushes back against the body with an equal and opposite force. This is explained by Newton's 3rd law of motion which states that for every action there is an equal and opposite reaction.

Purposes: 1) to compare the pattern and magnitude of vertical GRFs for a series of vertical movements of the body or body segments, 2) to consider the relative contribution of individual segment motions to vertical jump performance, and 3) to consider how a countermovement enhances vertical jump performance.

Vertical Jump Kinetics: The basic mechanical principle to be studied in this exercise is Newton's 2nd law of motion:

$$\Sigma \mathbf{F} = \mathbf{ma}$$

where ΣF represents the summation of all forces acting on a body (i.e., *the net force*), **m** is the body's mass, and **a** is the acceleration of the body's center of gravity (CG). A simple model of the body illustrates the application of Newton's 2nd law to the vertical motion of an individual during a vertical jump:



$$\Sigma \mathbf{F} = \mathbf{m_b a_{cg}}$$

$$(\mathbf{GRF_v} - \mathbf{W}) = \mathbf{m_b a_{cg}}$$

where:

- $\mathbf{GRF_v}$ is the vertical component of the ground reaction force
- $\mathbf{W}$ is the person's body weight
- $\mathbf{m_b}$ is the person's body mass
- $\mathbf{a_{cg}}$ is the vertical acceleration of the CG.

Therefore, from Newton's 2nd law, we can see that if the upward push of the ground is equal to the earth's downward attraction (i.e., weight), the net force on the body equals zero and the resulting acceleration is zero. If the ground reaction force is greater than body weight, there is a net positive force acting on the body and the acceleration is positive. Finally, if the ground reaction force is less than body weight, the net force on the body is negative and the acceleration is negative.

Summarizing:
if $GRF_v = W$, then $F = 0$ (no net force) and $a_{cg} = 0$
if $GRF_v > W$, then $F > 0$ (net force upwards) and $a_{cg} > 0$
if $GRF_v < W$, then $F < 0$ (net force downwards) and $a_{cg} < 0$

In considering changes in both the speed of the body CG (i.e., increase or decrease in speed) and direction of movement, positive acceleration is reflected under three conditions:

1) increase in CG speed as the CG moves upward
2) decrease in CG speed as the CG moves downward
3) changing directions from moving downward to moving upward

Similarly, negative acceleration is reflected by two conditions:

1) decrease in CG speed as the CG moves upward
2) increase in CG speed as the CG moves downward
3) changing directions from moving upward to moving downward

Procedures: A series of vertical movements of the body and/or body segments will be generated while the subject stands on an electronic force platform, an instrument designed to measure the horizontal and vertical components of the ground reaction force. Considering only the vertical component of the GRF, a force platform essentially represents a sophisticated weighing scale. The movements to be studied include:

1a) Shoulder flexion: from a standing position, forcibly swing the arms up
1b) Shoulder extension: with the arms overhead, forcibly swing the arms down
2) Trunk extension: from a standing position with the hips flexed (i.e., bent over at the waist), rapidly extend the hips to return to an upright position
3a) Knee flexion: with the hands on hips, rapidly squat down
3b) Knee extension: from a squatted position, rapidly return to a standing position
4) Neck extension: from a standing position with the neck flexed (i.e., chin down), rapidly extend the neck
5) Plantar flexion: from a standing position, rapidly plantar flex the ankles
6) Squat jump (SJ): starting in a squatted position, perform a maximum vertical jump
7) Countermovement jump (CMJ): starting in a standing position, perform a normal countermovement vertical jump

Once the GRF data are collected, the class will break down into small groups for discussion of the patterns of the net force, acceleration, and changes in speed of the body for each of the conditions. Attached as part of this lab handout are representative curves for each of the movements that should resemble those collected for an individual from your analysis group. When you perform your data analysis for your lab report, base your analysis on the curves provided for you in this lab handout.

Data Analysis

Part A. Complete the following table by briefly describing for each of the time periods indicated on the GRF records: 1) the direction of CG movement, 2) the net force (e.g., GRF > W), 3) the resulting acceleration (positive or negative), and 4) the change in speed.

Movement Condition		Movement Direction	GRF_v vs W Net Force	CG Acceleration	Description of change in CG Speed
1a	A	up	GRF > W	positive	increase speed upward
	B	up	GRF < W	negative	decrease speed upward
1b	A	down	GRF < W	negative	increase speed downward
	B	down	GRF > W	positive	decrease speed downward
2	A	up	________	________	________________
	B	up	________	________	________________
3b	A	up	________	________	________________
	B	______	________	________	________________
4	A	up	________	positive	________________
	B	up	________	________	________________
5	A	up	________	positive	________________
	B	______	________	________	________________
6	A	up	________	________	________________
7	A	down	GRF < W	negative	increase speed downward
	B	down	________	________	________________
	C	up	GRF > W	positive	________________
	D	______	GRF = 0	________	________________
	E	______	GRF = 0	________	________________
	F	down	GRF > W	________	________________
	G	up	GRF > W	________	________________
	H	______	________	________	________________

Part B. Relative peak forces: Calculate the peak forces for each of the segment motions noted below as a percentage of body weight using the following relationships:

Arm flexion (condition 1A):

(Peak force _____ mm / Body Weight _____ mm) * 100 = _____%

Trunk extension (condition 2):

(Peak force _____ mm / Body Weight _____ mm) * 100 = _____%

Knee extension (condition 3b):

(Peak force _____ mm / Body Weight _____ mm) * 100 = _____%

Neck extension (condition 4):

(Peak force _____ mm / Body Weight _____ mm) * 100 = _____%

Ankle plantar flexion (condition 5):

(Peak force _____ mm / Body Weight _____ mm) * 100 = _____%

Part C. For the squat jump (condition 6) and the countermovement jump (condition 7), compute and report the relative peak force during the push-off phase as a percentage of body weight (i.e., [peak force / body weight] * 100) and the time of flight. Use the following conversion factor for estimating the time of flight: 10 mm = 0.2 s

Peak force Squat jump: _____ % CM jump: _____ %

Time of flight Squat jump: _____ sec CM jump: _____ sec

[Show your work in this area]

Part D. Using your time of flight information from part C above, compute the takeoff velocity and height that the center of gravity is raised for the squat and countermovement jumps.

[Show your work in this area]

Takeoff velocity (V_i) Squat jump: _____ m/s CM jump: _____ m/s

Height of jump (h) Squat jump: _____ m CM jump: _____ m

Assignment: Complete all analyses in Parts A-D. Also, turn in type-written answers to *each of the 3* questions that are presented below. The assignment is due at the beginning of your lab period, Wednesday, October 22.

1. A comparison of condition 1 with condition 2 shows similar fluctuations in the GRF_v. Briefly state how the relative magnitude of the acceleration of the body CG during these two conditions would compare. Comment on how you think the mass, displacement, and acceleration of the body segments being moved explain why the GRF_v of condition 1 is similar to that of condition 2.

2. The relative peak forces computed in part B of the data analysis for conditions 1(A), 2(A), 3b(A), 4(A), and 5(A) provide one way of assessing the relative contributions of arm swing, trunk extension, knee extension, neck extension, and plantar flexion to the vertical jump performance, respectively. Using the results of Part B of your data analysis, rank the contributions of these five segment motions from largest (1) to smallest (5). Now, using the results of the slightly more sophisticated analysis by Luhtanen and Komi (1978), rank the contributions of the same five segment motions to the jump performance.

Your data	**Segment motion**	**Luhtanen & Komi (1979)**	**Segment motion**
	__________ arm swing		__________ arm swing
	__________ trunk extension		__________ trunk extension
	__________ knee extension		__________ knee extension
	__________ neck extension		__________ neck extension
	__________ plantar flexion		__________ plantar flexion

3. Based on the results of Harman et al. (1990), which has a greater effect on vertical jumping performance, countermovement or arm swing? Provide specific details to justify your answer. How does the arm swing influence vertical jumping performance? Explain.

What to turn in:

- Completed lab including Part A and calculations for Parts B, C, and D.
- Type-written answers to questions 1-3.