# **GROUND REACTION FORCE**

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 the 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 or dish, a push-up exercise, raising your hand to ask a question, and jumping. Because of the importance of our interactions with the ground in the generation and modulation of our movements, the ground reaction force 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 (remember Newton's 3rd law of motion).

With this in mind, the purpose of this laboratory exercise is to examine the ground reaction force for some simple vertical movements of the body’s center of gravity. The exercise will help you gain a better understanding of how we ultimately interact with the ground to produce movement of the body. While we will focus on vertical motion in this exercise, the same principles apply to horizontal movement.

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

= mb **.** **a**cg

where represents the summation of all forces acting on the body (i.e., the net force), mb is the body's mass, and **a**cg 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 squatting motion, as if one were about to sit in a chair:

|  |  |
| --- | --- |
| Free body diagram of person standing | = mb **.** **a**cg  (GRFv - BW) = mb **.** **a**cg  where:  GRFv is the vertical ground  reaction force  BW is the person's weight  mb is the person's body mass  **a**cg is the vertical acceleration of the CG |

From Newton's 2nd law:

(GRFv - BW) = mb**.** **a**cg

we can see that if the upward push of the ground is equal to the downward pull of gravity (i.e., the weight of the body), *the net force* on the body equals zero and resulting acceleration is zero. If the ground reaction force is greater than the weight of the body, there is a *net* upwards force acting on the body and the acceleration is positive. Finally, if the ground reaction force is less than the weight of the body, *the net force* on the body acts downwards and the acceleration is negative.

Summarizing:

if GRFv = BW, then = 0 (no net force) and **a**cg = 0

if GRFv > BW, then > 0 (net force upwards) and **a**cg > 0 or positive

if GRFv < BW, then < 0 (net force downwards) and **a**cg < 0 or negative

In terms of changes in the speed of motion of the body, *positive acceleration* is reflected under two conditions (remember our discussion of linear acceleration - see lecture notes on linear kinematics & Ch. 10 of text):

1. the speed of the center of gravity of the body is increasing as the CG moves upward

2. the speed of the CG is decreasing as it moves downward

Similarly, *negative acceleration* is reflected by two conditions:

1. the speed of the CG is decreasing as it moves upward

2. the speed of the CG is increasing as it moves downward

# Example Ground Reaction Forces

Consider the movement depicted below, a rapid squatting movement. To the right of the stick figures is a graph of vertical ground reaction force for the movement. The dashed line indicates body weight.

(1) Rapid Squat mov’t starts mov’t stops

GRF

B

BW A

C

TIME

Portion A: The time the GRFv is below BW

Portion B: The time the GRFv is above BW

Point C: The point at which the GRFv crosses or is equal to BW

What is happening to the center of gravity of the body during portions A & B of the rapid squatting movement? Address how vertical speed/velocity is changing during each portion of the movement, and state whether the vertical acceleration of the center of gravity is positive, negative or zero. For example, during portion A, is the speed increasing, decreasing, or constant, and is the velocity positive or negative. Also is the acceleration positive, negative, or zero. Answer the same questions for portion B. Also, explain what is happening at point C (when GRF = BW) in terms of acceleration (positive negative, or zero). Write your answers in the space below. Also, mark on the graph where you would find the greatest negative acceleration, the greatest positive acceleration, and the greatest velocity.

1. In portion A, the COG(BW) is greater than the GRF which means there is a negative acceleration as well as a negative velocity. Body weight is going down, which means the speed of COG is increasing. At the peak of portion A it has the greatest negative acceleration. Then it goes upward and turns positive to reach position C. At position C at some point during the rapid squat there is a constant velocity because there is no acceleration, meaning COF and GRF are equal. After position C, GRF increases while COG(BW) decreases. In portion B, the COG(BW) is less than the GRF which means there is a positive acceleration as well as a positive velocity. Body weight is going up which means the speed of COG is decreasing. At the peak of portion B it has the greatest positive acceleration. The velocity is positive because the BW is moving upwards however it turns negative again when it heads downward towards the end of the graph.

# **2). Rapid stand.**

Draw the graph of GRFv against time for a rapid movement upward to a fully erect standing position from a static squatting position (plot this electronically in the space below). Again, explain the different portions of the graph in terms of vertical speed and acceleration, just as you did for the rapid squat. So, label each portion of the graph as before; that is, the portion above BW, below BW, and when it is equal to BW

A graph on a piece of paper

Description automatically generated

1. In portion A, the COG(BW) is less than the GRF which means there is a positive acceleration as well as a positive velocity. Body weight is going up which means the speed of COG is increasing. At the peak of portion A it has the greatest positive acceleration. Then it goes downwards and turns negative to reach position C. At position C at some point during the rapid squat there is a constant velocity because there is no acceleration, meaning COF and GRF are equal. After position C, GRF increases while COG(BW) decreases. In portion B, the COG(BW) is more than the GRF which means there is a negative acceleration as well as a negative velocity. Body weight is going up which means the speed of COG is decreasing. The velocity is positive because the BW is moving upwards however it turns negative again when it heads downward towards the end of the graph.

# **3). Weightlifting**

Imagine standing on a scale whilst holding a weight. Think about what happens to the scale reading as you lift the weight overhead and then lower it back down. Fill out the chart below as you do this activity.

Is the scale less than, equal to Is acceleration +, (-) or 0

or greater than BW

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Moving weight up Starting up greater than BW +

Mid-range equal to BW 0

Slowing down Less than BW -

Moving weight down Starting down less than BW -

Mid-range equal to BW 0

Slowing down greater than BW +

Draw the shape of the GRF vs Time for both the above activities. Show a dotted line representing body weight

A graph on a piece of paper

Description automatically generated

# **4. Elevator Ride**

Imagine standing rigid on a scale in an elevator as it moves up from the ground floor, stops at the top floor, goes back down, and stops again at the ground floor. What happens to the scale reading as the elevator starts up, continues up with constant velocity, stops, starts down, continues down with constant velocity, and stops again.

Is the scale less than, equal to Is acceleration +, (-) or 0

or greater than BW

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Moving up Starting up greater than BW +

Continuing up equal to BW 0

Slowing down less than BW -

Moving down Starting down less than BW -

Continuing down equal to BW 0

Slowing down greater than BW +

Draw the shape of the GRF vs Time for both the above activities. Show a dotted line representing body weight

A paper with writing on it

Description automatically generated

A paper with writing on it

Description automatically generated

Which elevator on campus has the greatest acceleration? Check at least three elevators.

To calculate acceleration, apply Newton’s second law: = mb **.** **a**cg

Therefore, (GRFv - BW) = mb **.** **a**cg

You should enter the force in Newtons and mass in Kg

1 lb = 4.45 N and 1 Kg = 2.2 lb

Show the calculations in full and do not forget the appropriate units.

Elevator Ride (Upwards)

1 lb = 4.45N 1kg = 2.2 lbs

**Admin Building**

((150 lbs x 4.45)-(120lbs x 4.45)) = (120/2.2kg) x a

667.5N - 534N = 54.55kg x a

(667.5N-534N)/54.55= a

**2.45m/s^2 = a**

**Biology Building**

((135lbs x 4.45) - (120lbs x 4.45)) = (120/2.2kg) x a

600.75N - 534N = 54.55kg x a

(600.75N - 534N)/ 54.55 = a

**1.22m/s^2 = a**

The admin building elevator had the greatest acceleration because it had the greatest distance covered per second per second.