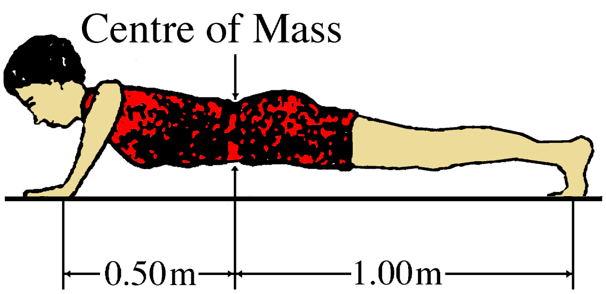
PHYS1002 Fundamentals Mechanics
Lecture 8 : Solution to Pushup Problem

Problem

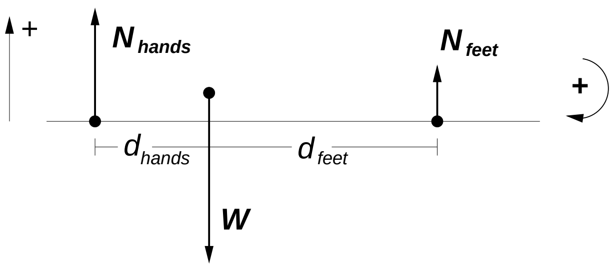


A 65 kg woman is horizontal in a push-up position.

What are the vertical forces acting on her hands and her feet?

Solution

The following diagram shows the forces on the woman.



Translational equilibrium (Newton's 2nd law) gives

$$\Sigma \mathbf{F} = 0 \tag{1}$$

Rotational equilibrium (no net torque acts) gives

$$\Sigma \tau = 0 \tag{2}$$

From (1), balancing vertical forces gives (positive upwards)

$$N_{hands} + N_{feet} - W = 0$$

From (2), balancing torques gives (clockwise rotation positive, and choose axis of rotation to be at centre-of-mass of woman, so that there is no torque due to her weight force)

$$N_{hands}\, d_{hands} - N_{feet}\, d_{feet} = 0$$

i.e.

$$\begin{aligned} N_{hands}\, d_{hands} &= N_{feet}\, d_{feet} \\ N_{hands} &= N_{feet}\, \frac{d_{feet}}{d_{hands}} \end{aligned}$$

Substitute for N_{hands} in (1)

$$N_{feet}\, \frac{d_{feet}}{d_{hands}} + N_{feet} - mg = 0$$

and so

$$\begin{aligned} N_{feet} &= \frac{mgd_{feet}}{(d_{hands} + d_{feet})} \\ &= \frac{65 \text{ kg} \times 9.8 \text{ ms}^{-2} \times 1.00 \text{ m}}{(0.50 \text{ m} + 1.00 \text{ m})} \\ &= 420 \text{ N} \end{aligned}$$

i.e. <u>the magnitude of the force on the woman's hands is 420 N</u>.

Substituting this back into (1) and rearranging gives

$$\begin{aligned} N_{hands} &= mg - N_{feet} \\ &= 65 \text{ kg} \times 9.8 \text{ ms}^{-2} - 420 \text{ N} \\ &= 210 \text{ N} \end{aligned}$$

i.e. <u>the magnitude of the force on the woman's feet is 210 N</u>.

This makes sense - the sum of the magnitudes of these two forces must equal the magnitude of the weight force, $W = mg = 630$ N. Additionally, since magnitude of torque is given by the product of magnitude of force and perpendicular distance, and torques around any axis must balance in this static situation, then if the woman's feet are twice as far from her centre-of-mass as her hands, the force on her hands must be twice that on her feet.