To lift it without acceleration a vertical displacement of height h, from position y_1 to y_2 in Fig. 6–11 (upward direction chosen positive), a person must do work equal to the product of the needed external force, $F_{ext} = mg$ upward, and the vertical displacement h. That is,

$$\begin{aligned} W_{ext} &= F_{ext}\, d \cos 0° = mgh \\ &= mg(y_2 - y_1). \end{aligned} \tag{6–5a}$$

Gravity is also acting on the object as it moves from y_1 to y_2, and does work on it equal to

$$W_G = F_G\, d \cos\theta = mgh \cos 180°,$$

where $\theta = 180°$ because $\vec{\mathbf{F}}_G$ and $\vec{\mathbf{d}}$ point in opposite directions. So

$$\begin{aligned} W_G &= -mgh \\ &= -mg(y_2 - y_1). \end{aligned} \tag{6–5b}$$

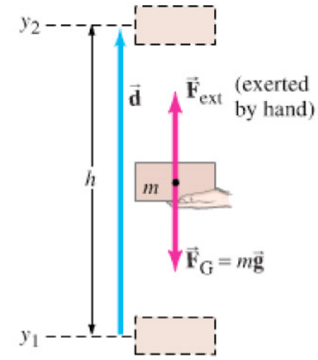

FIGURE 6–11 A person exerts an upward force $F_{ext} = mg$ to lift a brick from y_1 to y_2.

If we now allow the object to start from rest and fall freely under the action of gravity, it acquires a velocity given by $v^2 = 2gh$ (Eq. 2–11c) after falling a height h. It then has kinetic energy $\frac{1}{2}mv^2 = \frac{1}{2}m(2gh) = mgh$, and if it strikes a stake it can do work on the stake equal to mgh (work-energy principle). Thus, to raise an object of mass m to a height h *requires* an amount of work equal to mgh (Eq. 6–5a). And once at height h, the object has the *ability* to do an amount of work equal to mgh.

We therefore define the **gravitational potential energy** of an object, due to Earth's gravity, as the product of the object's weight mg and its height y above some reference level (such as the ground):

Gravitational PE

$$\text{PE}_{grav} = mgy. \tag{6–6}$$

The higher an object is above the ground, the more gravitational potential energy it has. We combine Eq. 6–5a with Eq. 6–6:

$$\begin{aligned} W_{ext} &= mg(y_2 - y_1) \\ W_{ext} &= \text{PE}_2 - \text{PE}_1 = \Delta\text{PE}. \end{aligned} \tag{6–7a}$$

That is, the work done by an external force to move the object of mass m from point 1 to point 2 (without acceleration) is equal to the change in potential energy between positions 1 and 2.

Alternatively, we can write the change in potential energy, ΔPE, in terms of the work done by gravity itself: starting from Eq. 6–5b, we obtain

$$\begin{aligned} W_G &= -mg(y_2 - y_1) \\ W_G &= -(\text{PE}_2 - \text{PE}_1) = -\Delta\text{PE}. \end{aligned} \tag{6–7b}$$

That is, the work done by gravity as the object of mass m moves from point 1 to point 2 is equal to the negative of the difference in potential energy between positions 1 and 2.

CAUTION
Potential energy belongs to a system, not to a single object

Potential energy belongs to a system, and not to a single object alone. Potential energy is associated with a force, and a force on one object is always exerted by some other object. Thus potential energy is a property of the system as a whole. For an object raised to a height y above the Earth's surface, the change in gravitational potential energy is mgy. The system here is the object plus the Earth, and properties of both are involved: object (m) and Earth (g).

Gravitational potential energy depends on the *vertical height* of the object *above some reference level* (Eq. 6–6). In some situations, you may wonder from what point to measure the height y. The gravitational potential energy of a book held high above a table, for example, depends on whether we measure y from the top of the table, from the floor, or from some other reference point.