The force exerted by the back muscles is represented by $\vec{\mathbf{F}}_{\mathrm{M}}$, the force exerted on the base of the spine at the lowest vertebra is $\vec{\mathbf{F}}_{\mathrm{V}}$, and $\vec{\mathbf{w}}_{\mathrm{H}}$, $\vec{\mathbf{w}}_{\mathrm{A}}$, and $\vec{\mathbf{w}}_{\mathrm{T}}$ represent the weights of the **h**ead, freely hanging **a**rms, and **t**runk, respectively. The values shown are approximations taken from Table 7–1. The distances (in cm) refer to a person 180 cm tall, but are approximately in the same ratio of 1:2:3 for an average person of any height, and the result in the following Example is then independent of the height of the person.

**EXAMPLE 9–9** **Forces on your back.** Calculate the magnitude and direction of the force $\vec{\mathbf{F}}_{\mathrm{V}}$ acting on the fifth lumbar vertebra for the example shown in Fig. 9–14b.

**APPROACH** We use the model of the upper body described above and shown in Fig. 9–14b. We can calculate $F_{\mathrm{M}}$ using the torque equation if we take the axis at the base of the spine (point S); with this choice, the other unknown, $F_{\mathrm{V}}$, doesn't appear in the equation because its lever arm is zero. To figure the lever arms, we need to use trigonometric functions.

**SOLUTION** For $\vec{\mathbf{F}}_{\mathrm{M}}$, the lever arm (perpendicular distance from axis to line of action of the force) will be the real distance to where the force acts (48 cm) multiplied by sin 12°, as shown in Fig. 9–14c. The lever arms for $\vec{\mathbf{w}}_{\mathrm{H}}$, $\vec{\mathbf{w}}_{\mathrm{A}}$, and $\vec{\mathbf{w}}_{\mathrm{T}}$ can be seen from Fig. 9–14b to be their respective distances from S times sin 60°. $F_{\mathrm{M}}$ tends to rotate the trunk counterclockwise, which we take to be positive. Then $\vec{\mathbf{w}}_{\mathrm{H}}$, $\vec{\mathbf{w}}_{\mathrm{A}}$, $\vec{\mathbf{w}}_{\mathrm{T}}$ will contribute negative torques. Thus $\Sigma\tau = 0$ gives

$$\begin{aligned}(0.48\,\mathrm{m})(\sin 12^\circ)(F_{\mathrm{M}}) &- (0.72\,\mathrm{m})(\sin 60^\circ)(w_{\mathrm{H}}) \\ &- (0.48\,\mathrm{m})(\sin 60^\circ)(w_{\mathrm{A}}) - (0.36\,\mathrm{m})(\sin 60^\circ)(w_{\mathrm{T}}) = 0.\end{aligned}$$

Solving for $F_{\mathrm{M}}$ and putting in the values for $w_{\mathrm{H}}, w_{\mathrm{A}}, w_{\mathrm{T}}$ given in Fig. 9–14b, we find

$$\begin{aligned}F_{\mathrm{M}} &= \frac{(0.72\,\mathrm{m})(0.07w) + (0.48\,\mathrm{m})(0.12w) + (0.36\,\mathrm{m})(0.46w)}{(0.48\,\mathrm{m})(\sin 12^\circ)}(\sin 60^\circ) \\ &= 2.37w \approx 2.4w,\end{aligned}$$

where $w$ is the total weight of the body. To get the components of $\vec{\mathbf{F}}_{\mathrm{V}}$ we use the $x$ and $y$ components of the force equation (noting that $30^\circ - 12^\circ = 18^\circ$):

$$\Sigma F_y = F_{\mathrm{V}y} - F_{\mathrm{M}} \sin 18^\circ - w_{\mathrm{H}} - w_{\mathrm{A}} - w_{\mathrm{T}} = 0$$

so

$$F_{\mathrm{V}y} = 1.38w \approx 1.4w,$$

and

$$\Sigma F_x = F_{\mathrm{V}x} - F_{\mathrm{M}} \cos 18^\circ = 0$$

so

$$F_{\mathrm{V}x} = 2.25w \approx 2.3w,$$

where we keep 3 significant figures for calculating, but round off to 2 for giving the answer. Then

$$F_{\mathrm{V}} = \sqrt{F_{\mathrm{V}x}^2 + F_{\mathrm{V}y}^2} = 2.6w.$$

The angle $\theta$ that $F_{\mathrm{V}}$ makes with the horizontal is given by $\tan\theta = F_{\mathrm{V}y}/F_{\mathrm{V}x} = 0.61$, so $\theta = 32^\circ$.

**NOTE** The force on the lowest vertebra is over $2\frac{1}{2}$ times the total body weight! This force is exerted by the "sacral" bone at the base of the spine, through the fluid-filled and somewhat flexible *intervertebral disc*. The discs at the base of the spine are clearly being compressed under very large forces. [If the body was less bent over (say, the 30° angle in Fig. 9–14b becomes 40° or 50°), then the stress on the lower back will be less (see Problem 35).]

If the person in Fig. 9–14 has a mass of 90 kg and is holding 20 kg in his hands (this increases $w_{\mathrm{A}}$ to $0.34w$), then $F_{\mathrm{V}}$ is increased to almost four times the person's weight ($3.7w$). For this 200-lb person, the force on the disc would be over 700 lb! With such strong forces acting, it is little wonder that so many people suffer from low back pain at one time or another.

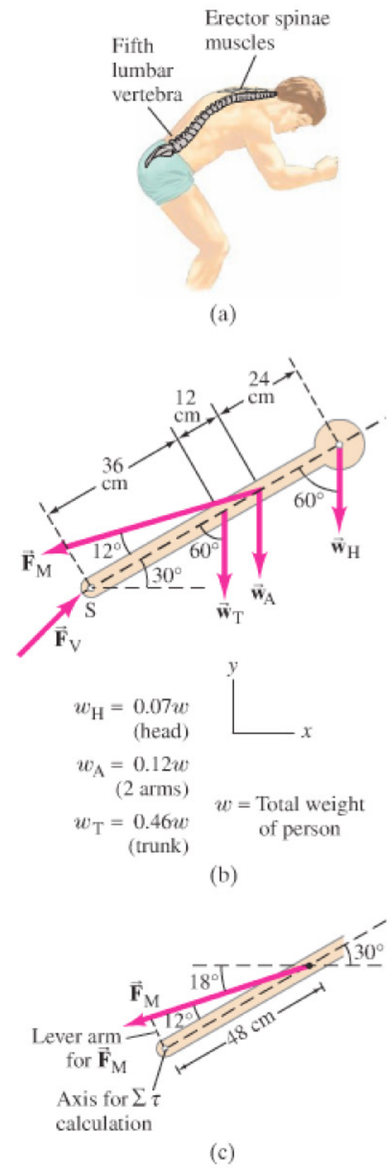


**FIGURE 9–14** (a) A person bending over. (b) Forces on the back exerted by the back muscles ($\vec{\mathbf{F}}_{\mathrm{M}}$) and by the vertebrae ($\vec{\mathbf{F}}_{\mathrm{V}}$) when a person bends over. (c) Finding the lever arm for $\vec{\mathbf{F}}_{\mathrm{M}}$.