Figure 2
When the ball is moving very fast, the player must exert a large force over a short time to change the ball's momentum and quickly bring the ball to a stop.

A change in momentum takes force and time

Figure 2 shows a player stopping a moving soccer ball. In a given time interval, he must exert more force to stop a fast ball than to stop a ball that is moving more slowly. Now imagine a toy truck and a real dump truck rolling across a smooth surface with the same velocity. It would take much more force to stop the massive dump truck than to stop the toy truck in the same time interval. You have probably also noticed that a ball moving very fast stings your hands when you catch it, while a slow-moving ball causes no discomfort when you catch it. The fast ball stings because it exerts more force on your hand than the slow-moving ball does.

From examples like these, we see that a change in momentum is closely related to force. In fact, when Newton first expressed his second law mathematically, he wrote it not as $\mathbf{F} = m\mathbf{a}$, but in the following form.

$$\mathbf{F} = \frac{\Delta \mathbf{p}}{\Delta t}$$

$$\text{force} = \frac{\text{change in momentum}}{\text{time interval}}$$

We can rearrange this equation to find the change in momentum in terms of the net external force and the time interval required to make this change.

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Topic: Momentum
Code: HF60988

IMPULSE-MOMENTUM THEOREM

$$\mathbf{F}\Delta t = \Delta \mathbf{p} \qquad \text{or} \qquad \mathbf{F}\Delta t = \Delta \mathbf{p} = m\mathbf{v_f} - m\mathbf{v_i}$$

force × time interval = change in momentum

This equation states that a net external force, **F**, applied to an object for a certain time interval, Δt, will cause a change in the object's momentum equal to the product of the force and the time interval. In simple terms, a small force acting for a long time can produce the same change in momentum as a large force acting for a short time. In this book, all forces exerted on an object are assumed to be constant unless otherwise stated.

The expression $\mathbf{F}\Delta t = \Delta \mathbf{p}$ is called the impulse-momentum theorem. The term on the left side of the equation, $\mathbf{F}\Delta t$, is called the **impulse** of the force **F** for the time interval Δt.

impulse
the product of the force and the time over which the force acts on an object

The equation $\mathbf{F}\Delta t = \Delta \mathbf{p}$ explains why proper technique is important in so many sports, from karate and billiards to softball and croquet. For example, when a batter hits a ball, the ball will experience a greater change in momentum if the batter keeps the bat in contact with the ball for a longer time. Extending the time interval over which a constant force is applied allows a smaller force to cause a greater change in momentum than would result if the force were applied for a very short time. You may have noticed this fact when pushing a full shopping cart or moving furniture.