Ski instructors should not underestimate the importance of understanding the principles that make a ski speed up, slow down, or change direction. This chapter defines some of these basic concepts and looks at how they are applied. It explains the forces acting on a skier when standing still, then in a straight run, to demonstrate the basic forces that set skiers into motion, speeds them up and slows them down. Finally it studies the changes in these forces when a skier turns.

3.1 FORCE

The term force describes something that causes a skier to undergo a change in speed or direction. It is simply anything that pushes or pulls on an object. This chapter discusses the interaction between the combination of skier and skis and the snow surface.

Two categories of forces are experienced when skiing:

INTERNAL FORCES
Forces generated by the skier through muscular-skeletal movements. These types of forces are covered in the Chapter 2 Skiing–A Sport of Movement pg. 38

EXTERNAL FORCES
Gravity, friction and the reaction forces from the snow. These are forces that act upon a skier. A skier must manage these forces through proactive and reactive movements to stay in balance.

3.1.1 MANAGING THE FORCES

A skier and the equipment they are wearing (boots, clothing, etc) is a skier’s mass. This term is defined as a measurement of the quantity of matter an object possesses. This is slightly different than the term weight, which is a measurement of gravity’s effect on the object. An object with greater mass will have a larger weight because gravity is a constant.
The skier's **centre of gravity** is defined as the mean location of the weight of a body. For our purposes it is the theoretical point in the body where all mass acts as if it is concentrated. As a skier moves, this point may be inside of or outside of the body (see diagram 1). Where this point is located determines where the skier is balanced on the skis. When we describe the location of the skier's centre of gravity we describe its relationship to the **base of support**. This is defined as the portion of the ski or skis under the foot or feet. A skier standing still on flat ground is in balance when their centre of gravity is centred over their base of support from a lateral and fore/aft perspective.

A skier standing still on two flat skis, with their centre of gravity balanced over the middle of their base of support will be evenly balanced over two feet. The result of this is felt as pressure against the soles of both feet. Pressure is represented by the equation $P = \frac{F}{a}$ where $P = $ Pressure, $F = $ Force, and $a = $ area (units are N/m²). It is important to understand that if the contact area is reduced or the force is increased the pressure is increased. For example, when a skier lifts their right ski off the snow they reduce the surface area ($a$), but force ($F$) - the skier's weight - remains unchanged, therefore pressure ($P$) has increased on the left ski.

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*Diagram 1 • The Centre of Gravity*

*Diagram 2 • Gravity and the skier in motion*

The relationship of these two reference points will become increasingly important as the skier moves from the static example above, to being in motion.

In general the force that puts a skier in motion is gravity. A skier in a straight run is pointed down a shallow slope and therefore begins to move. Since gravity ($G$) always pulls us towards the centre of the earth, we will break the effects of gravity into a few components to show how it puts the skier into motion (see diagram 2).

$G_1$ is the component of gravity that puts the skier into motion. $G_1$ is parallel to the slope. $G_2$ keeps the skier in contact with the terrain. $G_2$ is perpendicular to the slope.

As skiers straight run down a gentle slope they begin to speed up. This is an example of acceleration. Acceleration is defined as a change in velocity, or speed in a particular direction, of an object. Acceleration happens when there is an external force applied to an object. In the case of the skier in
When skiers attempt a spin or 360 they are creating rotational momentum. This is defined as a quantity of rotation of a body. Once they begin to spin they will continue to spin until an outside force, such as friction, acts on them. Similarly they will continue to spin in the same direction until an outside force acts on them to change direction. When performing a 360 in the air a skier gains rotational momentum through takeoff and continues to spin in the same direction until landing. While rate can be affected, the direction of rotation will remain constant. As in the example of a straight run, given everything else is equal, a larger skier will spin for longer than a smaller skier.

In a ski turn we move both linearly (momentum) and about an axis (rotational momentum). Any change in the velocity of a body in motion, speeding up, slowing down or change of direction is due to the application of an outside force. That outside force can come from friction, wind resistance or deflection from terrain or another body.

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3.2 FORCES ACTING UPON THE SKIER IN A TURN

Sir Isaac Newton identified a set of laws that involve forces and acceleration, momentum and inertia.

- The first law states that an object in a state of motion tends to stay in that state of motion unless an external force acts upon it. This is the definition of inertia. In a straight run a skier will continue to go straight unless an external force causes the skier to turn. A skier will not change direction unless a force acts upon them. This means that the skis need to interact with the snow so that the snow can push the skier around the turn.

- The second law defines the relationship between mass, force and acceleration. This is represented by $F=ma$. This states that the direction of the force is the same as the direction of the acceleration. An example is a skier in a wedge turn engages the inside edge of the left ski which causes the snow to push against the left ski. The direction of this external force is to the right causing the skier to veer to the right.

- The third law states that every action has an equal and opposite reaction i.e. that all forces involve two objects and the force acts with equal strengths but in opposite direction on both. In a ski turn the two objects are the skier (and skis) and the snow. The force from the snow pushes on the ski causing the skier to change direction. The skier responds with muscular tension to resist and balance against that force.

"Without G1 the skier would not be in motion" is an example of Newton's first law.

"The skier accelerates in the direction of G1" is an example of Newton’s second law.

"The snow pushes back at the skier with an equal amount and in an opposite direction of G2" is an example of Newton’s third law.

Note that the steeper the slope the larger G1 will become, therefore the skier will accelerate more rapidly.

As a ski is tipped up on edge it penetrates the snow and the snow presses back on the ski causing it to bend. The force from the snow pushing on the ski causes the skier to change direction. If we imagine a turn as a portion of a circle, the force acting on the skis is directed towards the centre point of the turn or the axis of rotation. This is called centripetal force and is responsible and essential for turning (see diagram 4).
Any change in speed or size of the turn will change the amount of centripetal force. For example two ways to increase the centripetal force acting on the skier would be to either go faster or tighten the radius of the turn.

Through the course of the turn the skier experiences the feeling of being pulled to the outside of the turn. This sensation is called centrifugal force. This feeling of being pulled to the outside can be described as the equal and opposite to the force from the snow that is causing the skier to turn, centripetal force (see diagram 5).

Centrifugal force is only experienced by the skier and is not observed from outside of that frame of reference. If the ski was to disengage from the snow the skier would not be thrown towards the outside of the turn, as the direction of centrifugal force would imply, but rather travel in a straight line on a tangent to the arc of the turn. This is the direction of the skier’s inertia at the point that the edges disengaged. This effect can be very helpful in communicating what a skier should feel through the course of a turn.

3.3 THE PATH OF THE CENTRE OF GRAVITY IN RELATION TO THE BASE OF SUPPORT

In all turns centripetal force is present. This force acting towards the centre of the turn means skiers must move their centre of gravity inside the path of their base of support to stay in balance.

Therefore to balance against the force from the snow in a ski turn the centre of gravity must move inside the turn, which means when turning, the path of the centre of gravity will always be inside the path of the base of support (see diagram 6).

Lateral movement of the centre of gravity towards the centre of the turn is called inclination. As the skier inclines towards the centre of the turn, the path of the centre of gravity and base of support diverge. Some inclination is present in all turns.
The degree skiers can incline, or move their centre of gravity inside their base of support is defined by the amount of centripetal force acting on them. The faster the skier goes or the tighter the radius, the greater the centripetal force (see section on centripetal force), and therefore the more a skier can incline. In a wedge turn the skier is travelling at a fairly slow speed and centripetal force, while present, is low in intensity. Therefore the path of the centre of gravity is close to the path of the base of support. A basic parallel turn is faster and the centripetal force is greater therefore the path of the centre of gravity and base of support are further apart. Finally, in a dynamic medium radius turn, the force from the snow is more intense. This requires the skier to incline a great deal to stay in balance, resulting in the centre of gravity and base of support following quite different paths (see diagram 7).

For turning to take place the ski must grip the snow to some degree. This is dependent on:
- the ski must penetrate the snow
- the snow must hold and push back against the ski

On hard pack the snow compacts very little and reacts and pushes back very quickly. In powder and softer snow the reaction that creates turning, happens slower because the snow must compact to a point where it can push back against the ski, and cause the skier to turn.

In a turn a skier experiences the combined effects of gravity and centrifugal force. This can be called the resultant force (ref. Ron LeMaster, Ultimate Skiing, 2009). This is the average of centrifugal and centripetal forces. The faster the skier travels through a turn the greater the centripetal and centrifugal forces. This results in the angle of the resultant force also being more inclined and allows for the skier to incline further. This is important to understand, because to what degree the ski grips is determined by the angle of the ski to this force.

The reaction force from the snow is always perpendicular to the ski. When the ski is tipped up and penetrates the snow it creates a groove in the snow to support the ski. Assuming that the snow can hold the force of the ski and the ski, or platform is 90 degrees or greater to the resultant force, the ski will hold and carve. At angles greater than 90 degrees to the resultant force the ski will carve a tighter radius. If the ski is tipped to less than 90 degrees to the resultant force the ski will begin to slip and skidding will occur. The more the platform angle decreases the more the ski will skid. Controlling the relationship of the angle of the platform (skis) to the resultant force is controlling the amount of skidding a skier will use in a turn.
3.4 PRESSURE AND PRESSURE MANAGEMENT – THE SUM OF IT ALL

When a beginner skier balances the upper body towards the outside foot, or a more advanced skier accelerates down a blue slope making medium radius turns, the force increases. In both instances the skier experiences this increase in force as an increase in pressure.

At a fundamental level learning to ski is learning to harness and manage the forces acting upon the skier and the pressure those forces create. As skiers develop skills and ability they develop a desire to go faster and to steeper terrain. This will result in the skier experiencing greater forces acting upon them in the form of greater pressure. Skiers create and manage these forces through co-ordinating skilful movements of the body. The more ski instructors understand about the forces that are at work when skiing, the more able they will be to choose movement areas that will create successful outcomes.

Recommended reading for further studies

- Ultimate Skiing – Ron LeMaster, 2009 Human Kinetics
- The Physics of Skiing; Skiing at the Triple Point – David A. Lind and Scott P. Sanders, 2004 Springer