SPORT SCIENCE SCIENTIFIC INVESTIGATIVE STUDY: MOVEMENT ANALYSIS

Motor Program
The following study will analyse the skill of cornering as part of the sport of road cycling. The purpose of this sporting skill is to enable a cyclist to successfully, safely and efficiently navigate a road bike around a corner.

Aim
To correctly analyse the skill of cornering by means of biomechanical analysis, thus enabling errors to be detected and an evaluation to be made regarding the overall effectiveness of the sub-routines performed by the subject.

Background Research
A motor program is the set of instructions held in memory that is sent to the muscles and results in movement (Amezdroz, 2010, P.5). The motor program analysed in this study is the skill of cornering as part of the overall motor skill of road cycling.

Subroutines are component parts of a reasonably complex skill (Amezdroz, 2010, p. 5). In regard to cornering, there are many subroutines that make up the overall skill, the subroutines of this skill are:

1. **Approach corner:** the first subroutine of cornering is approaching the corner. Approaching the corner involves identifying and analysing the corner ahead and processing such information. The initial subroutine of approaching the corner ensures the cyclist is aware of the corner ahead, the width of the road, the apex of the corner, the road surface and presence of hazardous objects such as potholes or road kill. The key movement in this subroutine is to stop pedalling in preparation for the corner.

2. **Ride in the dropped handlebars:** A cyclist should then position their hands in the lower part of the handlebars (see figure 1). According to Irvine (2015) the positioning the hands in the drops allows the cyclist to have greater control over the bikes line and enables the individual to become more aerodynamic as they are in a more streamlined position, which minimises wind resistance and allows the individual to cut through the air at a greater speed whilst exerting less energy.
3. **Position feet:** According to Bikeradar (2017) a cyclist should subsequently position their inside foot at the top of the pedal stroke in the 12 o’clock position and the outside foot at the bottom of the pedal stroke in the 6 o’clock position (see figure 1) to prevent the inside foot from making contact with the ground when the cyclist leans into the corner.

4. **Distribute weight:** A cyclist should then plant their weight on their outside foot. This allows the cyclists weight to be distributed evenly over both wheels. With the cyclist’s body weight planted on the pedal facing the outside of the corner, an individual is increasing the traction of the tyres on the road (Bikeradar, 2017).

![Figure 1](image)

5. **Cut the apex of the corner:** A good approach is to start wide then lean into the apex of the turn (Bikeradar, 2017). A cyclist should ride from the opposite side of the road or lane toward the point of the corner and “cut the apex,” essentially cutting the corner, this ensures speed is maintained when cornering.

6. **Lean the bike and not the body:** Stieda (2010) outlines that a cyclist enters a corner, they should use the arms and hands to lean the bike into the corner, lowering the bike toward the road, whilst leaning the upper body in the opposing direction toward a more upright position to maintain stability and balance.
7. **Return the body and bike to an upright position:** As the cyclist exits the corner the rider should return the bike to the upright, vertical position (Coach Levi, 2014) where the body should be directly positioned over the bike frame.

8. **Get out of the saddle:** after exiting the corner a cyclist should get out of the seat in order to apply maximum force and power onto the pedals and achieve greater acceleration when leaving the corner in order to build up speed (BikeRadar, 2017).

**Classification of skill**

A motor skill can be classified based on its characteristics (Amezdroz, 2010, p.6). To classify a skill one must consider the movement precision, type of movement and environmental predictability of the motor skill.

The first classification system distinguishes skills as either fine or gross motor skills based on the muscles involved in the movement (Amezdroz, 2010, p.6). The skill of cornering would be considered a gross motor skill as it involves the entire body, for example the cyclist must use their legs to build and maintain speed when entering and exiting the corner, the arms to position and lean the bike into the corner and the upper body to maintain stability.

The second classification system is based on the stability of the environment and classifies skills as either open or closed along a continuum (Amezdroz, 2010, p.6). The skill of cornering would be classified as a reasonably closed skill as the cyclist is performing the skill in a predictable environment in which they have full control over the speed and timing of the skill, thus the skill is internally paced. It is important to consider, however, that the skill is also influenced significantly by environmental factors such as the wind direction and strength and the unpredictability of the road surface and quality, for example unforeseen potholes. It is also important to recognise that in different circumstances, for example when the skill is performed during a race or on an open road, external factors such as other cyclists, cars and pedestrians are all unpredictable factors that would make this skill more open than closed due to the increased unpredictability of the environment in which the skill is being performed.
The third classification system is based on whether the skill has a specific beginning and ending (Amezdroz, 2010, p. 7). The sport of cycling would be classified as a continuous skill as the nature of cycling brings together discrete skills in a repetitive movement, however the specific skill of cornering would be classified as a discrete skill as the skill has a distinct beginning and ending. The beginning is the riders first subroutine of approaching the corner and the end being the final subroutine of the cyclist exiting the corner.

**Biomechanical Analysis**

Biomechanical analysis is the assessment of the proper use of techniques in sport and science (Dictionary of Sport and Exercise Science, 2007. P.29). As part of biomechanical analysis one must consider the kinematics involved in the skill, which is the area of biomechanics that studies the description of motion (McGinnis, 1999, p76 cited in E Teaching, 2007) and the kinetics concerning the skill which is the area of biomechanics that studies influences on the movement of a body (E Teaching, 2007).

The first step of biomechanical analysis is stating the objective of the skill. The objective of cornering on a road bike is to successfully, efficiently and safely navigate the bike around a corner whilst maintaining as much speed as possible.

Identifying movement patterns is the next step in a biomechanical analysis. There are a number of patterns of movement associated with cornering in cycling, including sitting and pushing and pulling. The entry and exit of a corner performed by a cyclist would be classified as a combination of a sitting and pushing and pulling patterns as the rider is positioned in a seated position and uses their legs to apply force to the pedals and thus accelerate.

Subsequently, as part of a biomechanical analysis one must break down the skill into phases (Amezdroz, 2010, p.184). The key phases of cornering on a road bike include the entry phase, which include approaching the corner, the execution phase which encompasses distributing weight, positioning the feet and leaning the bike into the corner and finally the and exit phase, which incorporates straightening the bike, taking a wide line out of the corner and getting out of the seat to accelerate (BikeRadar, 2017).
Kinematics
There are different types of motion, all of which can be classified as linear motion, angular motion or general motion (E Teaching Physical Education, 2007). The skill of cornering is classified as general motion as it is a combination of linear and angular motion. The motion of the body and bike riding through a corner in a straight line, where all parts of the body move in the same direction is an example of linear motion and the legs rotating around the hip axis and the feet rotating around the ankle axis as the cyclist pedals when entering and exiting the corner in order to accelerate are examples of angular motion.

A specific factor affecting the motion of the cyclist and bike through the air include the shape of the cyclist and bike. Streamlined shapes travel more effectively in the air and travel further due to less drag force pulling the cyclist backwards (E Teaching, 2007).

Kinetics
Kinetics is the area of biomechanics that studies the influences on the movement on a body (E Teaching, 2007). It is important to consider the mass, forces, levers, balance and stability when analysing the influences on the movement of a body.

Mass is defined by E Teaching (2007) as the amount of matter that makes up an object. When cornering on a road bike, the mass that one must consider includes the mass of the cyclist and the mass of the bike. Force is the pushing and pulling effect of a body that can cause change (Hay, 1993 cited in E Teaching, 2007). Forces that influence the movement of the bike body when cornering, include the force applied to pedals on the bike in order to accelerate when exiting the corner, the force applied to the brakes in order to slow down and forces from the environment such as gravity and air resistance.

Newton's First Law of Motion states, “a body at rest will remain at rest, and a body in motion will remain in motion unless it is acted upon by an external force.” This law means that an object cannot start, stop, or change direction without a force acting upon it (Lucus, 2014).

The Second Law of Motion states that the rate of change of acceleration to a body is proportional to the force applied (E Teaching, 2007). It states, “the force acting on an
object is equal to the mass of that object times its acceleration.” This is written in mathematical form as \( F = ma \), where \( F \) is force, \( m \) is mass, and \( a \) is acceleration (Lucus, 2014).

Newton’s Third Law of Motion describes what happens to a body when it exerts a force on another body. It states, “For every action, there is an equal and opposite reaction.” Forces always occur in pairs, so when one body pushes against another, the second body pushes back just as hard (Lucus, 2014).

A lever is a rigid rod or body segment that rotates around an axis (Amezdroz, 2010, p.150). When considering the skill of cornering, the levers involved include the bones in the legs; particularly the femur, tibia and fibula to apply force to the pedals and the arms, which enable the cyclist to control the bike and position, maintain balance and stability.

According to Amezdroz (2017, p.151) balance is the ability to control your state of equilibrium. Balance is particularly important in the skill of cornering as an individual’s centre of gravity shifts as the rider navigates the corner at maximum speed and leans in the opposing direction to the corner in order to maintain dynamic stability. Centre of gravity is defined as the point at which a body can be balanced (Dictionary of Sport and Exercise Science, 2007, p.44). Base of support refers to the area beneath an object or person that includes every point of contact that the object or person makes with the supporting surface (Khadir, et al., 2011). The base of support in reference to cornering are the two wheels of the bike that are in contact with the ground, more specifically the tyres. The greater the base of support the greater the degree of stability (Smyth et al., 2006, p.130 cited in E Teaching, 2007).

**Method**

**Equipment:**
- Road Bike
- Helmet
- Cleats (cycling shoes)
- Camera (Ipad)
Coloured/white dots for marking points of rotation/axis
Skill analysis program (Huddle)

Recording Procedure:

1. Establish a suitable location to film the skill of cornering on an open and safe road.
2. Situate the camera horizontally, parallel to the corner. Approximately 10m from corner in order to film the entirety of the skill.
3. When cyclist is ready, begin filming from a stationary point of view. Film the entire duration of the skill until the cyclist performs the final subroutine.
4. After filming from a stationary point of view film the cyclist cornering using a panning technique. When cyclist is ready, begin filming using the panning technique following the cyclist as they enter the corner and exit the corner.
5. Next, film from a ‘front on’ perspective.
6. Finally, film from behind capturing a “back on” perspective of the cyclist cornering.

Participant Details
Age: 17
Gender: Female
Stage of Learning: Associative stage of learning
Sporting Level: The subject being analysed in this study has a considerable amount of knowledge and experience regarding the skill of cornering as part of road cycling. The individual is at a state and national level in the sport of road cycling and trains for the sport on a daily basis, practicing the skill of cornering regularly.

Discussion and Results
Performance analysis is the investigation of actual sports performance, with the aim being to develop an understanding of sports that can inform decision-making, enhance performance and inform the coaching process (Haines, 2013). Performance analysis has a number of applications, predominantly concerned with tactical and technical evaluation, movement analysis, detecting errors and coach and athlete education.
(Haines, 2013). Analysing performances allows an individual to verify sound techniques and identify errors (Amezdroz et al, 2010). The steps involved in Biomechanical analysis include determining the objective of the skill, using observation techniques, identifying movement patterns, breaking a skill down into phases, detecting errors and identifying starter mechanisms. The three steps that will be analysed in the discussion include observation, detecting errors and identifying starter mechanisms.

**Subroutine 1:** The initial subroutine in the skill of cornering is approaching the corner. As part of this subroutine an individual stops pedalling in preparation for the corner and identifies and processes the important information involved with corner ahead, for example the angle and road surface. Although the cyclist stops pedalling and applying force to the pedals which turns the wheels, based on Newtons 1st law of motion the bike will continue in its forward state of motion moving toward the corner, this is because the moving body has inertia. Newton's first law of motion states that "an object at rest stays at rest and an object in motion stays in motion with the same speed and in the same direction unless acted upon by an unbalanced force,” thus although the cyclist stops pedalling in preparation for the corner the bike continues in its state of motion. The subject successfully executed the first subroutine.

**Subroutine 2:** The following subroutine involves the anatomical position of flexion as seen in figure 1.3. When the cyclist positions their hands in the dropped handlebars, they decrease the angle of the elbow joint by bringing the humerus closer to the radius and ulna bones in the forearm, as a result flexion of the elbow joint is evident (Human Anatomy, 2010). The cyclist acquires this position for two key reasons. Firstly, lowering the hands and arms to grip the dropped handlebars allows the cyclist to lower their centre of gravity. The lower the centre of gravity is, the more stable the object. The higher it is the more likely the object is to topple over (Keith Gibbs, 2016), therefore by positioning the hands in the drops the cyclist is increasing their stability when leaning into the corner. Secondly, positioning the hands in the dropped handlebars changes the shape of the projectile in motion, which is the cyclist’s body. When the cyclist lowers their hand position the cyclists back becomes relatively flat and they are less upright, thus the cyclist is more aerodynamic. Streamlined shapes travel more
effectively in the air due to less drag force pulling the projectile backwards (E Teaching, 2007).

The subject made a number of errors when executing this subroutine. Although, the cyclist successfully decreased the angle of the elbow joint in order to lower their centre of gravity and reduce drag force, the comparison between figure 1.3 and 1.4, which exhibits former professional cyclist Cadel Evans, highlights the subject’s errors. As seen in figure 1.3 the angle of the subject’s elbow joints are approximately 130°, comparatively in figure 1.4 Cadel Evans’ elbow joint on his outside arm is an acute angle of 50° and the elbow joint of his inside arm is an angle of 130°. Cadel’s position allows him to lower his centre of gravity further than the subject being analysed by reducing the angle of flexion of the elbow joint and thus allowing him to acquire a lower position on the bike. His decreased angles of the elbow joints also allow him to further minimise the drag force of the air by becoming more streamlined and reducing the frontal surface area.

**Figure 1.3** displays the subject with their hands positioned in the dropped handlebars. **Figure 1.4** exhibits professional cyclist Cadel Evans positioned in the dropped handlebars.

(Reed, 2015).
Subroutine 3: the cyclist exhibits the anatomical position of extension when they position their outside leg in the 6 o’clock position at the bottom of the pedal stroke. When the rider moves their inside leg into the 12 o’clock position in preparation for the corner the rider is displaying flexion. The subject successfully executed this subroutine. The extension of the outside leg and flexion of the inside leg ensures that when the cyclist leans into the corner and decreases the angle between the road and bike frame the inside foot does not clip the ground, which according to Newton’s first and second laws would result in the body in motion (i.e. the cyclist) to discontinue in its state of motion due to the opposite upward force applied by the ground to the pedal resulting in the cyclist displacing their centre of gravity which would result in the cyclist losing their stability.

Figure 1.5 exhibits the subject’s foot and leg position in preparation for the corner

Subroutine 4: The fourth subroutine of distributing weight is the dominant factor in determining the center of mass of both the cyclist and bike (Vernier, 2015). The greater mass of the cyclist when compared to the bike means the cyclist’s distribution of weight and position will have a greater influence on the centre of gravity than the bikes position when cornering. The subject exhibited in figure 1.6 displays the rider shifting their centre of gravity in the opposing direction to the bike in order to keep the centre of gravity over the tyres, which serve as the base of support. By planting the weight on the pedal facing the outside of the corner (see figure 1.6), the rider is increasing the traction the tyres have on the road (Cycling inform, n.d.). By shifting their centre of weight over the bike the cyclist is enhancing their dynamic stability when cornering. The following subroutine displays the anatomical positions of extension where the
angle of the knee joint on the outside leg is increased and flexion where the angle of the knee joint on the inside leg is decreased.

The thin tyres on a road bike mean that the base of support is smaller when compared to alternative bikes such as mountain bike or motorbikes. The narrow tyres on the road bike mean that the rider has a lesser degree of stability due to a smaller base of support. As figure 1.6 displays, the rider successfully distributes their weight by shifting their centre of gravity in the opposing direction to the bike which enables the subject to maintain stability.

**Figure 1.6** exhibits the rider distributing their weight evenly over the tyres, which serve as the base of support

![Cyclist has planted their weight on their outside foot](image)

**Subroutine 5:** As figure 1.7 highlights the subject makes a number of errors when assuming the correct line through the corner. According to Coach Levi (2015) the goal when cornering is to make the turn as straight as possible and an individual does this by entering the turn as wide as possible, cutting straight through the apex, and exiting as wide as possible. By taking the correct line and maximising the angle of the corner the cyclist minimises their use of the brakes in order to slow down as a means of cornering at a sharper, more acute angle, which involves more technicalities. According to Newton’s first law applying the brakes during a corner would be
applying a force to the wheels, which would change the projectile’s state of motion and thus slow the rider down.

Figure 1.7 displays the subjects error in following the correct line through the corner, as the image displays the rider fails to enter the corner on the correct angle which affects the projectile’s pathway.

Subroutine 6: In relation to kinetics, the sixth subroutine of ‘leaning the bike and not the body’ is associated with the mass of the cyclist and the forces acting on the cyclist including gravity, the friction between the tyres and road and the centrifugal force as the cyclist corners (see figure 1.8). As the cyclist is of greater mass than the bike, it is important that the centre of gravity (centre of mass) of the rider is leant in the opposing direction to the bike, this movement ensures the cyclist can achieve dynamic stability throughout the corner, thus preventing the cyclist from falling into the corner and onto the road. The correct execution of the subroutine ‘leaning the bike and not the body’ is exhibited in figure 1.8 where the subject successfully leans the bike into the corner and
shifts their centre of gravity in the opposite direction in order to maintain dynamic stability. A recommendation that could be made to improve the subject’s execution of the following subroutine would be for the cyclist to keep the inside knee close to the bike frame (Coach Levi, 2015) instead of splayed out away from the midline of the body as seen in figure 1.8. Abduction of the inside knee where the cyclist moves the knee away from the top tube of the bike frame transfers the centre of gravity away of the cyclists torso and into the corner which could potentially result in the cyclist losing stability and falling into the corner as the mass of the inside leg causes the cyclist to become unbalanced.

Figure 1.8 depicts the angles of the bike as the cyclist leans the bike into the corner. The diagram shows the cyclist leaning in the opposing direction to the bike.

Subroutine 7: figure 1.9 displays the subject executing the subroutine of returning the bike perpendicular to the road surface, where each side of the bike creates a $90^\circ$ angle with the road. The cyclist uses their levers in the form of arm bones to control the bikes position and return the bike to a vertical position when exiting the corner. The cyclist’s centre of mass is now over the centre of the bike frame, which maximises the cyclist’s
dynamic stability as to when the cyclist is cornering and is required to shift their centre of mass in the opposing direction.

**Figure 1.9** exhibits the cyclist returning the bike to an upright position where the bike is perpendicular to the road making a $90^\circ$ angle with the road on either side of the bike.

![Image of cyclist in corner](image)

Subroutine 8: When exiting the corner, the cyclist uses their levers in the form of leg bones to apply force to the pedals in order to accelerate. The cyclist achieves this by decreasing and increasing the angles of the knee joint, to execute pushing and pulling movement patterns. Figure 2 displays the cyclist’s left leg executing the movement pattern of pushing and the anatomical position of extension as the rider increases the angle between the femur, tibia and fibula to an angle of $146^\circ$. The right leg demonstrates the movement pattern of pulling as the cyclist pulls the pedal up and displays the anatomical position of flexion as the rider decreases the angle of the knee joint to an angle of $87^\circ$. The bike will continue in its state of motion after the corner according to Newton’s 1st law of motion, in order to change the state of motion and accelerate a force must be applied. According to Newton’s 2nd law, in order to accelerate at a faster rate greater force must be applied by the cyclist when exiting the corner. If the subject and
bike’s mass equals 64 kilograms and the rider accelerates by 10km/hr (2.778m/s) then the force applied is 64 x 2.778=177.79N. The reaction of the road pushing forward on the wheel as the wheel pushes backward relative to the road, overall pushing the bike forward is an example of Newton’s third law. In order to maintain dynamic stability, the rider situates there centre of gravity over the centre of the upright, vertical bike. As the bike is now upright, the tyres have greater surface area in contact with the road and therefore the supporting base of the cyclist is greater resulting in a greater degree of stability (Smyth et al, 2006, p.130 as cited in E Teaching, 2007).

**Figure 2** displays the movement patterns of pushing and pulling and the anatomic positions of flexion and extension.

The subroutine of accelerating out of the corner is an example of general motion as it is a combination of both linear and angular motion (E Teaching, 2007). Linear motion is being performed by the cyclist in the subroutine as the rider exists the corner and looks to accelerate when getting out of the saddle taking a straight line where all the body parts of the cyclist move in the same direction along the road (E Teaching, 2007). Angular motion is being executed in this subroutine, when the individual’s femur rotates on the hip joint, which is an internal axis of rotation. The cyclist users the levers in the form of leg bones to generate speed by applying force to the pedals in order to accelerate out of the corner.
In reference to the kinetics involved with this subroutine, the forces involved with the execution of this skill include the forces produced by muscular contractions in the legs, which are applied to the pedals of the bike, and the forces produced by the environment, which include gravity, air resistance, and the ground reaction force. The mass of the cyclist and bike will determine how much force is required for the cyclist to change its state of motion and accelerate, which refers to Newton’s Second Law of Motion: $\text{Force} = \text{mass} \times \text{acceleration}$. The amount of force applied by the cyclist will determine the degree of acceleration when exiting the corner. Based on Newton’s second law, a cyclist and bike with a greater mass would require greater force to accelerate compared to a cyclist and bike of a lower mass.

As the cyclist applies force to the pedals in order to accelerate out of the corner it results in the chain rotating the rear wheel in a clockwise direction. The wheel, which is in contact with the road, pushes back by rotating in the opposite direction relative to the ground. The friction between the tyre and the road results in the road pushing forward on the wheel. According to Newton’s Third Law of motion the ground pushes in the opposite direction (forwards) on the tyre and this results in the bicycle accelerating forwards (Physicservello, n.d.).

**Figure 2.1** displays the forces acting on the cyclist as they accelerate out of the corner.
Starter mechanisms are certain movements that may be used in a skill that would appear to have little relevance to the efficient performance of the skill (Amezroz et al., 2010, p.186). Although the skill of cornering can be identified as a discrete skill with a distinct beginning and end, it is a skill performed during the continuous sport of cycling. As the skill of cornering is simply a component of cycling performed during the ride no starter mechanisms before initiating the skill of cornering can be identified.

Conclusion/recommendations

Recommendations for future studies would include using a high definition camera for recording the skill as part of the biomechanical analysis in order to obtain higher quality footage, which would enable more precision and accuracy when analysing the biomechanics involved in the skill. Conclusively, this study, which analysed the skill of cornering on a road bike using biomechanical analysis, was overall an insightful study. Breaking down the skill into its subroutines and following the steps of biomechanical analysis enabled errors to be detected, which proved to be a very interesting aspect of the study because by detecting the errors the subject made it was possible to recognize the impact the errors had on the kinematics and kinetics involved in the skill. For example, thorough the comparison made between the subject and professional cyclist Cadel Evans it was identified that the subject needed to decrease the angle of flexion of the elbow joint when gripping the dropped handlebars which directly related to the shape of the cyclist’s body when cornering which is a factor affecting the projectile motion of the cyclist moving through the air. The study highlighted the science behind executing what seems a simple skill and stressed the interrelationships that the subject’s errors had on the kinetics and kinematics involved in the skill.
Reference List


Bibliography (read/support work but not cited)


