Biomechanics Sample Problems

Forces
1) A 90-kg ice hockey player collides head-on with an 80-kg ice hockey player. If the first person exerts a force of 450 N on the second player, how much force does the second player exert on the first? \(-450 \text{ N}\)

2) How much force must be applied by a kicker to give a stationary 2.5-kg ball an acceleration of 40 m/s/s? \(100 \text{ N}\)

3) A 65-kg runner had a maximal vertical ground reaction force of 1700 N while running at moderate pace. What was the runner's weight in Newtons? \(637 \text{ N}\) What is the maximal vertical ground reaction force when expressed in multiples of body weight (1 body weight is the weight of the runner). \(2.67 \text{ times greater than body weight}\)

4) A high jumper with a body weight of 712 N exerts a force of 3000 N against the ground during takeoff. How much force does the ground on the high jumper exert? \(3000 \text{ N in the opposite direction}\)

5) A track athlete running at fast pace had an instantaneous resultant force of 2800 N acting through the heel during heel strike. If the angle of the resultant force was 120 degrees with respect to the horizontal, what were the horizontal and vertical forces acting on the heel? Estimate his body mass if you know that in general vertical ground reaction force found in running are about 4.3 times the value of body weight. \(-1400 \text{ N horizontal}; 2425 \text{ N vertical}; 57.5 \text{ kg}\)

6) The coefficient of friction between a basketball shoe and a court is 0.56, and the normal reaction force acting on the shoe is 350 N. How much horizontal force is required to make the shoe slide? \(>196 \text{ N}\)

7) A 70-kg skier is in a tuck position and moving down a 20-degree hill. Air resistance applies a resultant force of 15 N against the movement of the skier. The coefficient of friction between the skis and the snow is 0.09. What is the resultant downhill force acting on the skier? \(161 \text{ N downhill}\)

8) (Use \(g=-10\)) If a 70 kg person was sitting on a swing (centered evenly in the middle between the two ropes), what was the force being supported by each vertical rope (in Newtons)? \(350 \text{ N each}\) If the same person was sitting in the middle of a hammock, and each rope had an angle of 30 degrees with respect to the horizontal, how much force was each rope supporting? (Note: Force in the rope is not the same in the two situations.) \(700 \text{ N each}\)

9) An 85 kg cyclist (person + bike) was traveling at a constant speed level road. Upon starting up a hill with a 15-degree inclination, the cyclist stopped pedaling and coasted. What was the total downhill force acting on the cyclist considering the coefficient of friction between the tires and the road is 0.1? \(136 \text{ N downhill}\)
10) The coefficient of static friction between a sled and the snow is 0.19, with a coefficient of dynamic friction of 0.16. A 25-kg girl sits on her sled facing down a 10-degree hill. What is the minimum push her friend needs to exert to start moving down the hill? After getting a push, does she continue to slide down the hill? Explain. 

>4 N push downhill to start moving; yes, she continues to slide after a push; \( F_{\text{downhill}} = 43 \text{ N}; F_{\text{static friction uphill}} = 47 \text{ N}; F_{\text{dynamic friction uphill}} = 39 \text{ N} \)

11) Two people are playing tug-of-war. Due to their choice of footwear, their coefficient of static friction is different. Participant 1 has a mass of 60 kg, a coefficient of static friction of 2.0, and can pull with a maximum force of 1000 N. Participant 2 has a mass of 80 kg and a coefficient of static friction of 1.2, and can pull with a maximum force of 1200 N. Who wins?

**participant 1 wins**

12) A football player pushed a 60 kg blocking sled with a constant horizontal force of 400 N. The coefficient of kinetic friction between the sled and ground is 0.5. How much horizontal force opposes the forward motion of the sled? **294 N** What is the sled's horizontal acceleration? (assume that the playing surface is level). **1.77 m/s²**

**Linear Kinematics**

1) A 75 kg jumper lands stiff-legged on the floor and changes his velocity from –4.5 m/s to zero in 0.15 seconds. Compute the average resultant force working on the jumper. **2250 N**

If he increased the impact time to 0.2 s, what happens to the resultant force working on the jumper? **1688 N**

2) If an athlete jumped 2 feet high and left the ground at an angle of 20 degrees with respect to the horizontal, how fast was the athlete going in the forward (positive horizontal) and upward (positive vertical) directions immediately after takeoff? **Vertical velocity = 3.46 m/s  Horizontal velocity = 9.51** If the height of takeoff was the same as the height of landing, how fast was the athlete going in the horizontal and vertical directions right before landing? **Vertical velocity = -3.46 m/s  Horizontal velocity = 9.51**

3) An Olympic diver drops from the 10 meter platform with an initial vertical velocity of 0.0 m/s. What was the vertical velocity of the diver immediately before he/she hits the water? **14 m/s** How long did it take the diver to reach the water? **1.43 s**

4) A long jumper leaves the ground at an angle of 25 degrees with respect to the horizontal with a resultant velocity of 30 ft/s. What was the horizontal velocity of the jumper at takeoff in m/s? **Horizontal velocity = 8.29** What was the vertical velocity at takeoff in m/s? **Vertical velocity = 3.86 m/s** How high did the CM rise above the point of takeoff? **0.76 m**

5) Two balls were thrown upward and were caught at the same height from which they were released. Ball A was thrown upward with a vertical velocity of 10 m/s. Ball B was thrown upward with a vertical velocity which was twice that of ball A. How far did each ball rise above the point of release? **Ball A: 5.1 m  Ball B: 20.4 m** How long did each ball stay in the air (total time)? **Ball A: 2.0 s  Ball B: 4.1 s**
6) If a shot is put an angle of 41 degrees relative to the horizontal with a velocity of 36 ft/s in the direction of the put, what will be the upward (vertical) velocity at the instant of release? 7.2 m/s  What will be the forward (horizontal) velocity? 8.3 m/s  How high (above the point of release) will the shot go? 2.64 m  What is the time it takes the shot to reach its maximum height? 0.73 s

7) If the shot in problem 6 is released from a height of 6 ft and later lands on the ground (height = 0.0 ft), what was the total time of flight? 1.69 s  How far did the shot travel horizontally? 14.0 m

8) What is the average speed of a breastroke swimmer who completes 100m in a time of 1:15? 1.3 m/s

9) What is the average velocity of a breastroke swimmer who completes 100m in a time of 1:15? 0 m/s since they start and finish in the same location

10) A ball is thrown vertically upward with a velocity of 15 m s\(^{-1}\). If the acceleration due to gravity is 9.8 m/s\(^2\), what is the velocity of the ball 2 seconds after being thrown? -4.6 m/s  Is the ball still going up or is it coming down? Down

10) An orienteer runs north at 5 m/s for 120 seconds, and then west at 4 m/s for 180 seconds. What is the resultant displacement with respect to the starting position? Provide an angle with respect to the north direction. 937 m at 50 deg

11) A skier was gliding downhill at 15 m/s. How long did it take her to ski the 630 m to the base of the hill? 10.5 s  A less proficient skier averaged 12 m/s down the slope. If they started together, how far behind the first skier was he by the time she got to the bottom of the hill? 126 m

12) The world record for the 24-hour run is about 160 miles. What is this distance in meters? 257,488 m  What is 24 hours in seconds? 86,400 s  What would be a runner’s average speed in going 160 miles in a day in m/s and min/mi? 2.98 m/s or 9:00/min

13) Bobsleds accelerate from rest to high speeds in a few seconds. If one sled’s speed increased from 0 to 32 m/s in 8 seconds, what was its average acceleration during that time period? 4 m/s\(^2\)  How far did the sled travel down the track in the 8 seconds? 128 m

**Projectile Motion**

1) A soccer ball is kicked with an initial horizontal speed of 5 m/s and an initial vertical speed of 3 m/s. Assuming projection and landing heights are the same, identify the following quantities (ignoring air resistance):
   a. The ball’s horizontal speed 0.5 seconds into its flight: 5 m/s
   b. The ball’s horizontal speed midway through its flight: 5 m/s
   c. The ball’s horizontal speed immediately before contact with the ground: 5 m/s
   d. The ball’s vertical speed at the apex of flight: 0 m/s
e. The ball’s vertical speed midway through its flight: 0 m/s
f. The ball’s vertical speed immediately before contact with the ground: -3 m/s
g. The ball’s velocity throughout the flight: -9.8 m/s

2) A rugby player attempts a kick after scoring a try. The ball was kicked at an angle of 60 degrees with an initial resultant velocity of 40 miles/hour (ignoring air resistance).
   a. What was the initial resultant velocity in meters/second? 17.9 m/s
   b. What was the initial horizontal velocity in m/s? 9.0 m/s
   c. What was the initial vertical velocity in m/s? 15.5 m/s
   d. If the player was 40 meters away from the goal, and the height of the horizontal bar was 3 meters, did the player score? Assume that the trajectory of the ball was on target! No

3) A soccer ball is kicked from the playing field at a 45° angle. If the ball is in the air for 3 seconds, what is the maximum height achieved (ignoring air resistance)? 11.0 m

4) A mountain biker encounters a deep gorge. He has “heard” that if he jumps off the log on the edge of his side of the gorge he can expect 50° for his trajectory. He has also “heard” that the other side of the gorge is 1 meter higher than the side he is on. He knows that he can ride to a maximum speed of 20 mi/hr on the trail approaching the gorge and off of log. Assuming what the rider “heard” is accurate, how wide can the gorge be for him to not drop down the gorge? 7.1 m

Momentum
1) Two ice skaters start out motionless in the center of the ice rink. They then push each other apart. The man (mass = 80 kg) moves to the right with a speed of 2.5 m/s. The woman moves to the left at some unknown speed.
   a) If her mass is 58 kg, calculate that speed. (assume frictionless ice) 3.45 m/s
   b) What has happened to the total momentum of the system (woman + man) during the push-off? It was maintained since the resultant external force was zero when considering both people.

2) Lineman A has a mass of 100 kg and is traveling with a velocity of 4 m/s when he collides head-on with Lineman B, who has a mass of 90 kg and is traveling at 4.5 m/s. If both players remain on their feet, what will happen? (Answer: B will push A backward with a velocity of 0.03 m/s)

Angular Kinematics
1) A golfer accelerates the club from the top of the backswing until impact with the ball with an average angular acceleration of 30 rad/s² for a period of 0.5 s. The radius of rotation is 1.1 m. Compute the angular velocity of the club at impact, the linear velocity of the club head at impact, and the radial acceleration of the club head at impact. 16.5 m/s

2) A champion hammer thrower rotates at a rate of 3.2 rev/s just prior to releasing the hammer.
a) If the hammer is located 1.6 m away from the axis of rotation, what is the centripetal acceleration experienced by the athlete? 646 m/s²
b) How much tension (i.e. force) is needed to produce this radial acceleration if the mass of the hammer is 7.26 kg? 4696 N

3) A speed skater increases his speed from 10 m/s to 12.5 m/s over a period of 3 seconds while coming out of a curve of 20 m radius. What are the magnitudes of his tangential, centripetal, and resultant accelerations as he leaves the curve? (Answer: \( a_t = 0.83 \text{ m/s}^2; a_c = 7.81 \text{ m/s}^2; a = 7.85 \text{ m/s}^2 \))

4) A kicker's extended leg is swung for 0.4 seconds in a counter-clockwise direction while accelerating at 200 deg/s². What is the angular velocity of the leg at the instant of contact with the ball? (Answer: 80 deg/s or 1.4 rad/s)

5) A 1.2 m golf club is swung in a planar motion by a right-handed golfer with an arm length of 0.76 m. If the initial velocity of the golf ball is 35 m/s, what was the angular velocity of the left shoulder at ball contact? Assume that the left arm and golf club form a straight line and that the initial ball velocity is the same as the linear velocity of the club head at impact. (Answer: 17.86 rad/s)

Angular Kinetics
1) A 65 kg gymnast begins to prepare for his dismount from the high bar by increasing his angular velocity by a factor of 3. By what factor does the centripetal force change? (you may assume that \( r \) does not change) It increases by a factor of 9

2) A pitched ball with a mass of 1 kg reaches a catcher’s glove traveling at a velocity of 28 m/s.
   a. How much momentum does the ball have?
   b. How much impulse is required to stop the ball?
   c. If the ball is in contact with the catcher’s glove for 0.5 seconds during the catch, how much average force is applied by the glove?
   (Answer: a. 28 kg m/s; b. 28 Ns; c. 56 N)

3) A 108-cm, 0.73 kg golf club is swung for 0.5 seconds with a constant acceleration of 10 rad/s². What is the linear momentum of the club head when it impacts the ball? (Answer: 3.9 kg m/s)

4) A volleyball player’s 3.7-kg arm moves at an average angular velocity of 15 rad/s during the execution of a spike. If the average moment of inertia of the extending arm is 0.45 kg m², what is the average radius of gyration for the arm during the spike? (Answer: 0.35 m)

5) The patellar tendon attaches to the tibia at a 20 deg angle, 3-cm from the axis of rotation at the knee. If the tension in the tendon is 400 N, what is the resulting angular acceleration of the 4.2 kg lower leg and foot given a radius of gyration of 30 cm for the lower leg/foot with respect to the axis of rotation at the knee? (Answer: 15.6 rad/s²)
6) A 60 kg diver is positioned so that his radius of gyration is 0.5 m as he leaves the board in a layout position with an angular velocity of 4 rad/s. What is the diver’s angular velocity when he assumes a tuck position, altering his radius of gyration to 0.25 m? (Answer: $\omega = 16 \text{ rad/s}$)

8. The knee extensors insert on the tibia at an angle of 30 degrees (from the longitudinal axis of the tibia), at a distance of 3 cm from the axis of rotation at the knee. How much force must the knee extensors exert to produce an angular acceleration at the knee of 1 rad/s$^2$, given a mass of the lower leg and foot of 4.5 kg, and a radius of gyration of 23 cm? (Answer: $F = 15.9 \text{ N}$)
**Torque Problems**

1) What is the torque on a bolt if you are pulling with a force of 200 N directed perpendicular to a wrench of length 25 cm? How does the torque change for a wrench of twice the length? **50 Nm, 100Nm**

2. In cycling, the torque generated about the crank axis depends on the magnitude of the force applied to the pedal and also the angle between the crank arm and the force vector. In the diagram below, an 800 N vertical force applied to the pedal will create a counter-clockwise torque of 140 Nm when the crank is at 90 degrees (where greatest torque is generated). How much torque will the same force generate when the crank is at 75 degrees and at 105 degrees? What torque will that same vertical force generate when the crank is at 180 degrees? (Answers: at 75 and 105 degrees, torque = 135.2 Nm, at 180 degrees, torque = 0)

3. What is the torque about the shoulder if the arm is held in an abducted position at 60 degrees from the body in the frontal plane while holding a 10 kg dumbbell? Assume that the mass of the arm is 6 kg, its center of mass is located 38 cm from the shoulder joint center, and the arm's total length is 80 cm. (Answers: torque of dumbbell = -69.3 Nm; torque of arm weight = -19.7 Nm; Torque at the shoulder = 89 Nm)

4. Short Essay Response: The torque you can apply to the rear wheel of your mountain bike depends on which gear you are using. Explain how and why the gearing of the back wheel affects torque.

5. A 35 N hand and forearm are held at a 45° angle to the vertically oriented humerus. The center of gravity of the forearm and hand is located at a distance of 15 cm from the joint center at the elbow, and the elbow flexor muscles attach at a distance of 3 cm from the joint center (assume that the muscles attach at an angle of 45° to the axis of the forearm). 
   a. How much force must be exerted by the forearm muscles to maintain this position? (answer: 175 N)
   b. How much force must the forearm flexors exert if a 50 N weight is held in the hand at a distance along the arm of 25 cm? (Answer: 591.7 N)

6. A hand exerts a force of 90 N on a scale at 32 cm from the joint center at the elbow. The triceps attach to the ulna at a 90° angle, and at a distance of 3 cm from the joint center. The weight of the forearm and the hand is 40 N with the forearm/hand center of gravity located 17 cm from the elbow joint center. Considering these conditions, how much force is being exerted by the triceps? Remember that you are interested in the forces acting on the forearm system. (answer: 733.3 N)

7. A therapist applies a lateral force of 80 N to the forearm at a distance of 25 cm from the elbow joint center. The biceps attaches to the radius at a 90° angle and at a distance of 3 cm from the elbow. 
   a. How much force is required of the biceps to stabilize the arm in position? (answer: 666.7 N)
b. What is the magnitude of the reaction force exerted by the humerus on

1. A figure skater is rotating with counterclockwise angular velocity in an overhead view. If her angular acceleration is clockwise at that time, this implies that:
   (a) she is not changing the speed of her rotation.
   (b) her rotation is speeding up.
   (c) her rotation is slowing down.
2. Which of the following is true?
   (a) If location is constant, velocity has to be zero.
   (b) If velocity is constant, acceleration has to change at a constant rate.
   (c) If acceleration is constant, velocity also has to be constant.
3. A bus is moving forward at 12.5 m/s. You are inside the bus, moving laterally relative to the seats in the bus (i.e., sideways from a seat on the right side of the bus to a seat on the left side of the bus) at 4.6 m/s. What is the value of your resultant velocity vector relative to the street?
   (a) between 0.00 m/s and 5.00 m/s
   (b) between 5.01 m/s and 9.00 m/s
   (c) between 9.01 m/s and 13.00 m/s
   (d) between 13.01 m/s and 16.00 m/s
   (e) more than 16.01 m/s
4. Two bobsledding competitors push their sled for 3.2 s with a combined horizontal force of 110 N. The mass of the sled is 65 Kg. Assume that there are no friction forces between the sled and the snow. Calculate the horizontal acceleration of the sled.
   (a) between 0.0 m/s2 and 2.0 m/s2
   (b) between 2.1 m/s2 and 4.0 m/s2
   (c) between 4.1 m/s2 and 7.0 m/s2
   (d) between 7.1 m/s2 and 8.5 m/s2
   (e) more than 8.6 m/s2
5. A 200 meter swimming race takes place in a 50 meter pool. Assume that the positive direction is the direction of swimming in the first stretch (first 50 meters). How will the acceleration of the swimmer be when the swimmer is slowing down to make his second turn, that is, as he approaches the 100 meter point of the race?
   (a) positive
   (b) negative
   (c) zero
6. If we ignore the effects of air resistance, the sum of the horizontal forces exerted on a gymnast while she is in the air:
   (a) is zero.
   (b) depends on the mass of the gymnast.
   (c) is equal to the weight of the gymnast.
   (d) depends on the current horizontal velocity of the gymnast.
7. Which of the free-body diagrams below is correct? The system is the soccer player who is kicking the ball; the ball is NOT a part of the system.
   (a) (b) (c) (d)
8. A cyclist is riding in the positive horizontal direction at 12.3 m/s on a horizontal level
surface. She encounters an air resistance force of 27 N. The actions on the pedals by the cyclist cause a backward force of 153 N to be exerted by the rear wheel on the ground. The mass of the cyclist-plus-bike system is 61 Kg. Calculate the horizontal acceleration of the center of mass of the system. (HINT: first make a free-body diagram of the system.)

(a) between -20.0 m/s² and -2.5 m/s²  
(b) between -2.4 m/s² and -0.4 m/s²  
(c) between -0.3 m/s² and +0.3 m/s²  
(d) between +0.4 m/s² and +2.4 m/s²  
(e) between +2.5 m/s² and +20.0 m/s²

9. _______________ is a direct measurement of inertia in translations.
   (a) force  
   (b) mass  
   (c) acceleration  
   (d) weight  
   (e) velocity

10. A motion in which velocity changes by the same amount with every second that passes by is called:
   (a) variably accelerated motion.  
   (b) uniform motion.  
   (c) uniformly accelerated motion.

11. If your location is changing from a positive value to a negative value, you can be sure only of one of the following things:
   (a) Your velocity is decreasing.  
   (b) Your acceleration is negative.  
   (c) Your velocity is positive.  
   (d) Your velocity is negative.  
   (e) Your acceleration is constant.

12. A weight lifter is making a vertical upward force of 925 N on a 50 Kg barbell. Calculate the vertical acceleration of the barbell. Hint: Draw first a free-body diagram of the barbell, putting all the forces exerted on the barbell. Then get the resultant of all the forces exerted on the barbell, and go on from there.
   (a) between 0.00 m/s² and 1.00 m/s²  
   (b) between 1.01 m/s² and 2.00 m/s²  
   (c) between 2.01 m/s² and 5.00 m/s²  
   (d) between 5.01 m/s² and 10.00 m/s²  
   (e) more than 10.01 m/s²

13. A break-dancer is spinning on his back, rotating about a vertical axis. Seen from above, the rotation appears as clockwise. In which direction will his angular velocity vector point?

14. A football player throws the ball, and at the instant of release the ball has horizontal and vertical velocities of 7.4 m/s and 3.6 m/s, respectively. How long will it take the ball to reach its peak height?
   (a) between 0.00 s and 0.10 s  
   (b) between 0.11 s and 0.50 s
(c) between 0.51 s and 2.00 s
(d) between 2.01 s and 8.00 s
(e) more than 8.01 s
15. The motion of the amusement park boat shown below is:
(a) rotation.
(b) curvilinear translation.
(c) rectilinear translation.
(d) general motion.
16. Which of the following statements is TRUE?
(a) In the absence of air resistance, the vertical velocity of a projectile is constant.
(b) The path of a projectile can be changed in mid-air without external forces from solids or fluids.
(c) In the absence of air resistance, the horizontal velocity of a projectile changes at a constant rate.
(d) If two projectiles are released with the same horizontal velocity, the one with the largest vertical velocity at release will land farther away.
17. What are the units for linear impulse?
(a) N·s
(b) Kg·s
(c) Kg·m
(d) Kg
(e) N·m
18. Biomechanics research in the automobile and aerospace industries is concerned mainly with:
(a) the effects of accelerations.
(b) the achievement of maximum performance.
(c) the mechanics of the workplace.
(d) the development of rehabilitation exercises.
19. Look at the statements below. If you think that one of them is incorrect, answer with the letter of the incorrect statement. If you think that all three statements are correct, answer with the letter "d".
When a force is exerted on a body:
(a) For a given mass, the larger the force, the larger the acceleration.
(b) For a given force, the larger the mass, the larger the acceleration.
(c) For a given mass, the larger the impulse, the larger the change in the velocity.
20. Annie Oakley from the Buffalo Bill traveling circus takes a shot with her rifle barrel in a perfectly horizontal orientation. The rifle barrel is at a height of 1.50 m above ground level, and the initial velocity of the bullet is: \( v_X = 530 \text{ m/s}; v_Y = 0 \). As she shoots, she accidentally drops a cartridge that she had placed (for later use) on top of the hat that she was wearing. The bullet that drops from the hat starts off from a height of 1.60 m above ground level, and its initial velocity is \( v_X = 0 \); \( v_Y = 0 \). If we assume that there is no air resistance on either of the two bullets, which bullet will hit the ground first?
(a) the bullet that was shot
(b) the bullet that was dropped
(c) Both will reach the ground at the same time.
21. A ski jumper is landing with a linear velocity vector \( v \). We want to break down the velocity vector into two components. Which of the following is a correct breaking down of vector \( v \) into two components \( c_1 \) and \( c_2 \)?
(a) (b) (c) (d)

22. The arm of a softball pitcher is rotating at 835 degrees/s. The distance between her shoulder and the ball is 0.67 m. What is the linear velocity of the ball?
(a) between 0.00 m/s and 1.00 m/s
(b) between 1.01 m/s and 3.00 m/s
(c) between 3.01 m/s and 6.00 m/s
(d) between 6.01 m/s and 10.00 m/s
(e) more than 10.01 m/s

23. The weight of any given body will be:
(a) larger on the Earth than on the moon.
(b) the same everywhere in the Universe.
(c) larger on the moon than on the Earth.

24. One second before a swimmer touched the end of the pool near the half-way point of a 100 m race in a 50 meter swimming pool, her velocity was 2.40 m/s. Two seconds after touching the end of the pool, her velocity was -3.35 m/s. What was her average acceleration during that whole period of time?
(a) between -5.00 m/s² and -0.50 m/s²
(b) between -0.49 m/s² and +0.10 m/s²
(c) between +0.11 m/s² and +0.50 m/s²
(d) between +0.51 m/s² and +2.00 m/s²
(e) between +2.01 m/s² and +5.00 m/s²

25. Linear kinematics studies translation and its causes.
(a) TRUE
(b) FALSE

1. After a full inhalation of air, some men still sink in fresh water.
(a) TRUE
(b) FALSE

2. What are the units for angular momentum?
(a) Kg·m² / s²
(b) Kg·m²
(c) Kg·m / s
(d) Kg·m² / s
(e) N·m

3. In the sequence shown below, the jumper flexed his knees and hip between images 6 and 7. If he had kept his legs straight and in the same orientation as in image 6, at the time of image 7 his head would have been:
(a) farther down and to the left than in the original jump.
(b) in the same place as in the original jump.
(c) farther up and to the right than in the original jump.

4. In general, one should expect a body builder to float:
(a) better than most other people.
(b) just as well as other people.
(c) worse than most other people.
5. Name one quantity which could be appropriately measured in N·m·s.
   (a) power
   (b) work
   (c) angular impulse
   (d) angular velocity
   (e) torque
6. Which of the following statements is FALSE?
   (a) The center of mass (c.m.) is the average position of the mass of a body.
   (b) During the airborne phase in the course of a jump, if you raise your arms, the c.m. of
       the whole body will go down as a reaction.
   (c) The c.m. can be outside the material of the body.
   (d) In a standing position, the c.m. of a person with fat thighs and thin arms will
       generally be lower than that of a person of the same standing height but who has thin
       thighs and fat arms.
7. A person is trying to close a door by making a force $F_1 = 87$ N at a distance $d_1 = 0.50$ m
   from the door hinge. Another person is trying to open the door by making a force $F_2 =
   135$ N at a distance $d_2 = 0.31$ m from the door hinge (see sketch below). What will
   happen?
   (a) The door will open.
   (b) The door will close.
   (c) The door will remain half open at a stalemate.
8. After takeoff, on the way up to the bar, a high jumper:
   (a) gains potential energy, while kinetic energy stays constant.
   (b) loses both potential energy and kinetic energy.
   (c) gains potential energy, and loses kinetic energy.
   (d) loses potential energy, and gains kinetic energy.
   (e) loses potential energy, while kinetic energy stays constant.
9. (For this question, assume that air resistance forces are negligible.)
   It is possible to change the path of the hips while a person is airborne.
   (a) TRUE
   (b) FALSE
10. (In this question, do not ignore the effects of fluid forces.) If a table tennis ball has
topspin, the spin:
   (a) will keep it in the air longer.
   (b) will bring it down to the table sooner.
   (c) will not have any effect on the time that the ball will spend in the air.
11. (For this question, think of the vertical acceleration of the person.) In the sequence
shown below, at the instant that the center of gravity reached its lowest position
(somewhere between images 4 and 5), the upward vertical force exerted by the ground on
the jumper was:
   (a) larger than the person’s weight.
   (b) equal to the person’s weight.
   (c) smaller than the person’s weight.
12. A woman is lying in a perfectly static position on her back, on top of a horizontal wooden board. (See the rough sketch below.) The board is resting on a block of wood at one end, and on a weighing scale at the other end. The mass of the person is $m_P = 48$ Kg; the length of the board is $L = 4.00$ m; the reading on the scale placed under the edge of the board closest to her head is 315 N; when the person gets off the board, the reading on the scale decreases to 45 N. Calculate the distance between the c.m. of the person and the edge of the board closest to the feet.

NOTE: The force registered by the scale has been altered from the value that it would have had in real life, to prevent you from guessing your answer by estimating the distance between the feet and the waist of the person: You have to use mathematics to calculate your answer!

HINT: The total torque exerted on the person-plus-board system with respect to the edge of the board closest to the feet must be zero. When the person is off the board, the total torque exerted on the board must also be zero.

The distance between the c.m. of the person and the edge of the board closest to the feet is:
(a) between 0.00 m and 0.70 m.
(b) between 0.71 m and 1.20 m.
(c) between 1.21 m and 1.70 m.
(d) between 1.71 m and 2.25 m.
(e) more than 2.26 m.

13. If an individual has a body volume of 62 liters and a weight of 650 Newtons, this person will float in fresh water.
(a) TRUE
(b) FALSE

14. In slow concentric conditions, the maximum force that a muscle can exert is
___________ the force that it can exert in fast concentric conditions.
(a) smaller than
(b) larger than
(c) the same as

15. A person draws a bowstring, and shoots an arrow at a bird that is passing directly overhead, but misses. Which of the following sequences defines best the energy transformations that take place?
(a) elastic --> chemical --> kinetic --> potential
(b) potential --> chemical --> kinetic --> elastic
(c) chemical --> potential --> kinetic --> elastic
(d) chemical --> elastic --> kinetic --> potential
(e) potential --> elastic --> kinetic --> potential

16. A gymnast is making many bounces on a trampoline. At what instant of each complete jump cycle will kinetic energy be largest?
(a) when the gymnast’s c.m. is at the lowest point of its motion
(b) when the gymnast’s c.m. is at the highest point of its motion
(c) when the gymnast’s feet are barely off the surface of the trampoline
(d) when the gymnast’s c.m. is half-way between the lowest and highest points of its
17. The gymnast in the drawing is maintaining her position without any motion at all. What muscles are acting at the hip joint while the gymnast maintains this position? (NOTE: A free-body diagram of the legs should help you to decide.)
   (a) the muscles marked as "a" in the drawing
   (b) the muscles marked as "b" in the drawing
   (c) neither the muscles marked as "a" nor as "b" in the drawing

18. The drawings below show the hand of a swimmer and its direction of motion (v) through the still water. Indicate which drawing shows the correct directions for the lift (L) and drag (D) forces exerted by the water on the hand.
   (a) (b) (c) (d) (e)

19. A basketball player is trying to intercept a high-flying ball with her right hand. Which of the following will NOT help her to reach it:
   (a) lowering her head as her right hand gets near the ball
   (b) obtaining, through her takeoff, a high parabola for the airborne path of her c.m.
   (c) making large downward forces on the ground with her feet during the takeoff phase
   (d) lifting one of her knees as her right hand gets near the ball

20. In an arm wrestling contest, the loser's muscles that are involved in the effort have predominantly:
   (a) eccentric muscle activity.
   (b) concentric muscle activity.
   (c) no muscle activity.

21. It is possible for a person to change the speed of rotation of the body after leaving the ground.
   (a) TRUE
   (b) FALSE

22. The equation \( E = \frac{1}{2} m v^2 \) expresses:
   (a) potential energy.
   (b) rotational kinetic energy.
   (c) elastic energy.
   (d) translational kinetic energy.
   (e) chemical energy.

23. In the drawing shown below, the subject is holding the dumbbell statically in place. The cross indicates the position of the center of mass of the upper-arm + forearm + hand system. The mass of the upper-arm + forearm + hand system was 8 Kg, and the tension exerted by the shoulder muscle was 450 N. The values of the distances shown were: \( d_1 = 0.04 \text{ m}; d_2 = 0.20 \text{ m}; d_3 = 0.31 \text{ m} \).
   Calculate the upward force exerted by the hand on the dumbbell.
   (HINTS: First, make a free-body diagram of the upper-arm + forearm + hand system -- do not make the dumbbell be part of the system.)
24. A person is carrying two buckets of water on a pole. The weight of one of the buckets is \( W_1 = 250 \) N, and it is at a distance \( d_1 = 1.60 \) meters from the mid-line of the person. The other bucket weighs \( W_2 = 180 \) N. Where should the second bucket be placed, on the other side of the body, for the buckets to be balanced? The second bucket should be at a distance of ____ from the midline of the body.
(a) between 0.00 m and 0.50 m
(b) between 0.51 m and 0.80 m
(c) between 0.81 m and 1.60 m
(d) between 1.61 m and 2.50 m
(e) more than 2.51 m

25. The action of a muscle is said to be eccentric when:
(a) the muscle maintains the same length while it is activated.
(b) the muscle lengthens while it is activated.
(c) the muscle tension force passes through the center of the joint.
(d) the muscle shortens while it is activated.
(e) both (c) and (d).

1. The support phase of a running step has to be executed in such a way that the c.m. will reach at least a certain moderate height in the non-support phase that follows. The main **purpose** (goal) of this is to:
(a) give the recovery leg enough time during the non-support phase to move forward and then to move actively backward relative to the body before the start of the next support phase.
(b) give the runner a larger downward vertical velocity just before starting the next support phase.
(c) increase the horizontal propulsive force in the second half of the support phase.
(d) give the runner a smaller downward vertical velocity just before starting the next support phase.

2. The sketch below shows the path followed by a discus after release. Look **carefully** at the direction of motion and the angle of the discus, and state if there is:
(a) a lift force exerted on the discus, marked by vector "a".
(b) a lift force exerted on the discus, marked by vector "b".
(c) a lift force exerted on the discus, marked by vector "c".
(d) a lift force exerted on the discus, marked by vector "d".
(e) no lift force exerted on the discus.

3. Which of the following statements is FALSE? In sprinting, it is good to:
(a) fully extend the knee of the support leg at the end of the support phase.
(b) bring the swinging leg actively downward and backward immediately before it makes contact with the ground.
(c) lift the knee of the swinging leg.
(d) reach forward with the foot of the swinging leg, to make it land as far as possible ahead of the body.

4. What is the main advantage that tall high jumpers have over short high jumpers?
(a) The centers of mass of tall high jumpers start their parabolas at a greater height.
(b) A tall high jumper should generally be expected to achieve a larger vertical velocity.
(c) Gravity pulls down on the tall high jumpers with a smaller force.
(d) The tall high jumpers can stay in the air for a longer time.

5. Consider a high jumper that takes off from the left leg (like almost all the examples given in class). If this high jumper, instead of the normal somersaulting angular momentum that high jumpers get, obtained only lateral somersaulting angular momentum (and zero forward somersaulting angular momentum), in which of the positions shown below would the trunk be at the peak of the jump? (The drawings show views seen from overhead, and the small circle represents the athlete’s head.)
(a) (b) (c) (d) (e)

6. A high jumper was trying to clear the bar. In the view seen in the figure below, the jumper was rotating counterclockwise. The jumper then moved the arms in the form shown in the drawing. This action of the arms:
(a) increased the overall speed of rotation of the whole body.
(b) made the legs move up faster.
(c) made the legs slow down their counterclockwise rotation.
(d) did not affect the motions of the legs.

7. Which of the following factors can’t contribute to produce a bad bar clearance in high jumping? If all of them can contribute to produce a bad bar clearance, answer "e".
(a) poor timing of the arching/un-arching
(b) large moment of inertia about the transverse axis
(c) a small amount of angular momentum
(d) weak arching over the bar

8. The forces exerted by the water on the hands of a swimmer who uses the front crawl technique are:
(a) propulsive and drag.
(b) resistive and lift.
(c) resistive and drag.
(d) propulsive, lift and drag.
(e) propulsive and lift.

9. The main objective of a sprinter during the ground support phase is:
(a) to increase the stride length.
(b) to minimize the air resistance force.
(c) to increase the stride frequency.
(d) to minimize ground braking forces and maximize ground propulsive forces.

10. In **long** jumping, the main reason why it is important to have a fast approach run is that:
(a) it will allow you to have more leftover horizontal velocity by the time you leave the ground.
(b) it will decrease the braking of horizontal velocity that occurs during the takeoff phase.
(c) it will increase the height that your c.m. parabola will reach after you leave the ground.
(d) it will stimulate the muscles of your takeoff leg.

11. In the sequence shown below, if the arms of the jumper were to swing violently clockwise from the position that they have in image 7, to a position behind the body, the feet of the jumper would land:
(a) at the same distance from the point of takeoff as in the original jump.
(b) nearer to the point of takeoff than in the original jump.
(c) farther from the point of takeoff than in the original jump.

12. Which of the following statements is **FALSE**? If all of them are true, answer "e".
The lateral lean that a high jumper has at the end of the run-up:
(a) contributes to make the c.m. of the jumper be lower at the start of the takeoff phase.
(b) helps to increase the vertical range of motion available to the c.m. during the takeoff phase.
(c) indirectly helps the athlete to be vertical at the end of the takeoff phase.
(d) is affected both by the curvature of the run-up and by the speed of the run-up.

13. In the front crawl swimming technique, the trunk should be kept aligned with the direction of the race, in order to:
(a) minimize the resistive forces exerted on the trunk.
(b) maximize the propulsive forces exerted on the arms.
(c) minimize the resistive forces exerted on the head during breathing.
(d) maximize the propulsive forces exerted on the legs.

14. Long jumpers should be recommended to try to "paw" backward on the ground as they plant the takeoff foot.
(a) **TRUE**
(b) **FALSE**

15. The height reached by a high jumper is determined mainly by:
(a) the vertical velocity of the high jumper at takeoff.
(b) the size of the resultant velocity of the high jumper at takeoff.
(c) the mass of the high jumper.
(d) the horizontal displacement of the high jumper while the body is in the air.
(e) the horizontal velocity of the high jumper at takeoff.

16. During a normal long jump takeoff phase, the athlete will try to:
(a) gain as much vertical velocity as possible.
(b) gain as much vertical velocity as possible, while losing as little horizontal velocity as possible.
(c) gain as much horizontal velocity as possible, while losing as little vertical velocity as possible.
(d) gain as much horizontal velocity as possible.
17. Which of the following statements is FALSE? If you think that they are all true, answer "e".
   (a) At the end of the run-up a high jumper should be running rather fast.
   (b) In the first half of the takeoff phase of a high jump, the athlete should make a large effort trying to resist against the flexing of the takeoff leg.
   (c) During the takeoff phase, a high jumper should swing the arms very hard.
   (d) At the end of the run-up the hips of a high jumper should be rather low.

18. In a view from the right side of a long jumper, the angular momentum of the athlete will usually be __________ during the airborne phase.
   (a) counterclockwise
   (b) zero
   (c) clockwise

19. During the second half of the takeoff phase of a high jump, the quadriceps muscles of the takeoff leg are mostly in:
   (a) eccentric conditions.
   (b) isometric conditions.
   (c) concentric conditions.

20. On a ball that has topspin, the Magnus effect will:
   (a) tend to make it come down to the ground later than if it had had no spin.
   (b) tend to make it come down to the ground earlier than if it had had no spin.
   (c) have no effect on the time that the ball will be in the air.

21. The four drawings below show a side view of the underwater pattern of motion of a butterfly-style swimmer’s hand relative to the water. The subject is swimming from left to right. Each drawing shows a different orientation of the hand at a single point of its path. Indicate which hand orientation would be most advantageous for the swimmer. (HINT: Draw the lift and drag forces for each drawing, and then see which of the hand orientations provides a resultant force that is most closely aligned with the direction of the race.)
   (a) (b) (c) (d)

22. During the first half of the takeoff phase of a high jump, the quadriceps muscles of the takeoff leg are mostly in:
   (a) eccentric conditions.
   (b) isometric conditions.
   (c) concentric conditions.

23. A high jumper should plant the takeoff foot:
   (a) aligned with the final direction of the run-up.
   (b) “toeing in” (i.e., “pigeon toed”) relative to the final direction of the run-up.
   (c) “toeing out” relative to the final direction of the run-up.

24. In the breaststroke swimming technique, the hands move:
   (a) outward, backward and inward relative to the body, and also relative to the water.
   (b) outward and inward relative to the body, and also relative to the water.
   (c) outward, backward and inward relative to the body, but outward and inward relative to the water.
   (d) outward and inward relative to the body, but outward, backward and inward relative to the water.
25. A sprinter covered the final 20 meters of a 100 meter race in 2.3 seconds. The wind was blowing in the same direction as the race was run, at a speed of 3.9 m/s. The force exerted by the air on the runner:
(a) pointed in the direction of the race.
(b) pointed against the direction of the race.
(c) was zero.