Acceleration

Introduction:

Acceleration is defined as the rate of change of velocity with respect to time, thus the concepts of velocity also apply to acceleration. In the velocity-time graph, acceleration is represented by the slope of the line, with the steepness and direction of the slope indicating the nature of the acceleration – whether it is positive, negative or zero, and thus indicating the relationship between them. Similar to velocity, acceleration is a vector quantity meaning that it is both magnitude and direction aware. The term acceleration is often used loosely associating it with speed but this is not the case. An object can be moving at speed yet not be accelerating i.e. it has a constant velocity. If the velocity of an object is not changing then no acceleration is occurring. The basic equation for acceleration is:

$$\text{Acceleration} = \frac{\Delta \text{ Velocity } (ms^{-1})}{\text{Time (s)}}$$

The International System of Units (SI) is a list of the various metric systems. SI is built on seven fundamental standards called base units. All other units are various combinations of these seven bases, attained by the multiplying, dividing or powering of the bases. As the common SI unit for velocity is meters per second (ms^{-1}) and the SI unit for time is seconds (s) then acceleration is usually measured as meters per second per second (ms^{-2}). However any unit of length divided by any unit of time yields an acceptable unit of acceleration e.g. km/hr/s.

As mentioned earlier, acceleration is a vector meaning it is direction sensitive. The direction of acceleration is determined by two main factors:

- Whether the velocity of the object is increasing or decreasing
- Whether the object is moving in a positive or negative direction

Any change in velocity results in an acceleration. When an acceleration value is positive, this does not necessarily mean that the object is speeding up. A positive acceleration can indicate either that the velocity of the object is increasing in a positive direction or decreasing in a negative direction. Alternatively, if the acceleration is negative, velocity can either be increasing in a negative direction or decreasing in a positive direction.

The general rule of thumb is that when the velocity of an object is increasing, acceleration is in the same direction as the velocity. However, when the velocity of an object is decreasing then acceleration is in the opposite direction to its motion. This is sometimes referred to as deceleration.

Objectives:

- Define and analyse acceleration in sport specific situations using the Quintic software
- To compare the accelerations in various sports situations

Methods:

- The videos have been digitised and calibrated using the Quintic software.
- Data has been exported to an excel file where it was used to calculate linear acceleration, horizontal acceleration and vertical acceleration. Graphs have been prepared using this information.

- Still images have been captured from videos to outline different stages of the exercise

> Functions of the Quintic Biomechanics and Coaching Software used:
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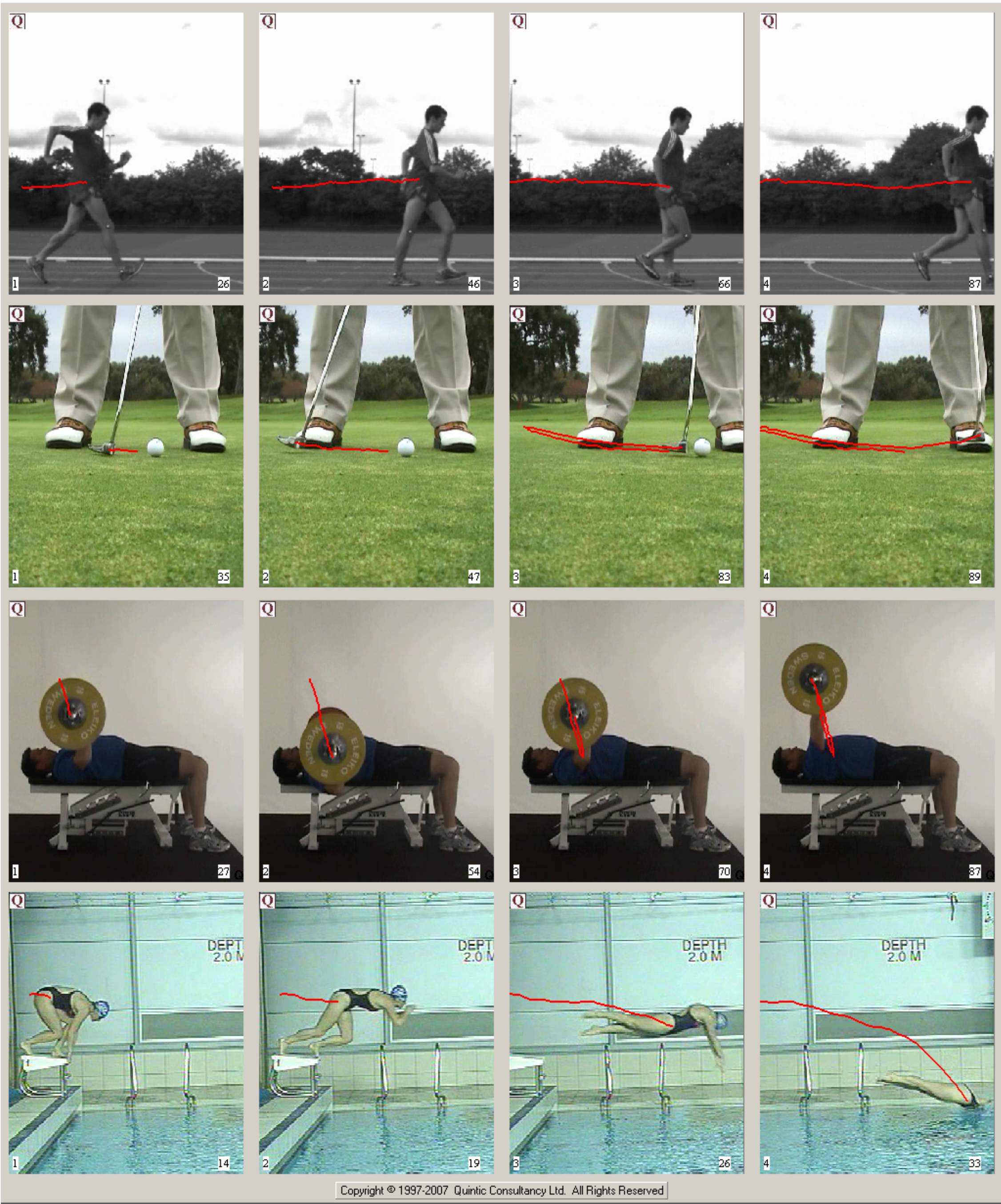
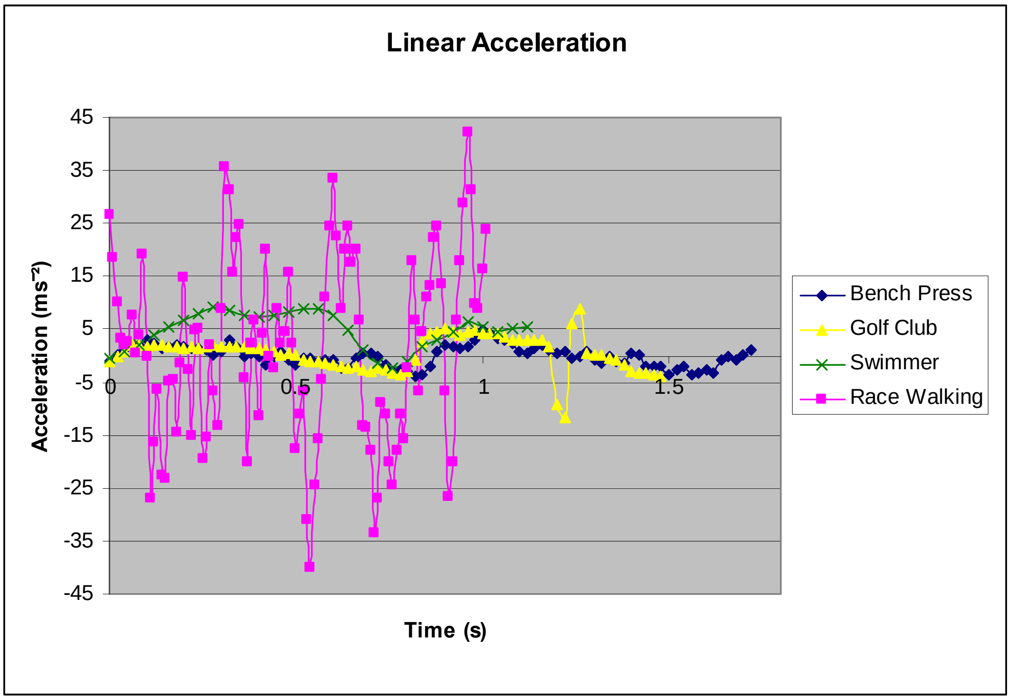
> - *1 Point Digitisation Module*
> - *Calibration*
> - *Interactive Graph and Data displays*
> - *Export Data*
> - *Multi-Image Capture*

Results:



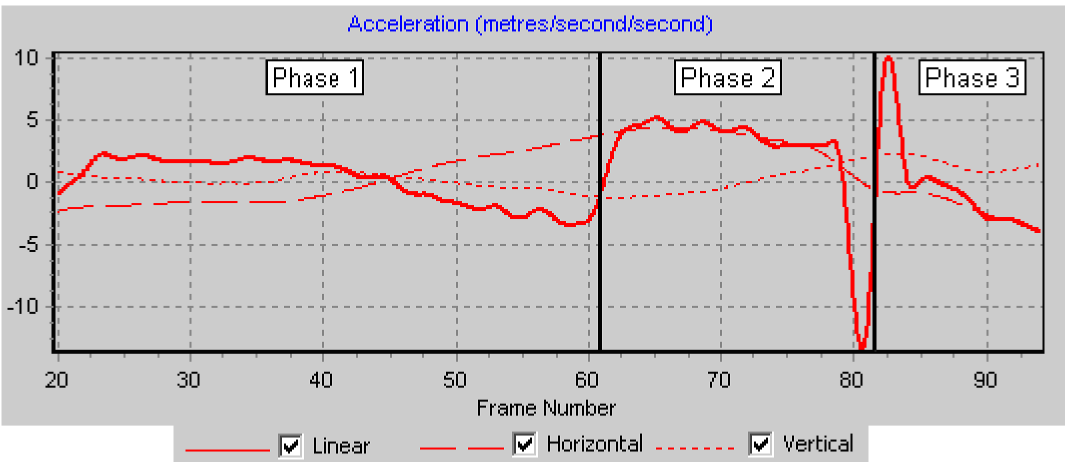
All the different accelerations (linear, horizontal and vertical) from the four activities – bench press, race walking, golf putt and swimming, were analysed using single point digitisation. Every frame of the video from the start of the movement to the end was digitised.



Graph 1: Linear Acceleration

Graph 1 shows the linear acceleration of the four sports. Race walking has the highest and most variable linear acceleration ranging from -40.07ms^{-2} to 42.35 ms^{-2}. The rest of the sports all experience significantly lower linear acceleration values, with swimming reaching a maximum acceleration of 5.71ms^{-2} and the other two sports reach minimal accelerations of 1.42ms^{-2} and 0.88ms^{-2} for the bench press and golf club respectively.

As stated in the introduction, acceleration is a vector and has both magnitude and direction. All horizontal and vertical acceleration graphs show the component acceleration in the respective directions. However, the linear acceleration graphs only show the magnitude of the acceleration. The direction of any linear acceleration is given by the resultant sum of horizontal and vertical accelerations.



Graph 2: Acceleration of the Golf Club

Graph 2 and figure 1 (below) illustrates acceleration of the golf club. This graph has been divided into three different phases of the golf swing during the putt shot. Phase 1 is the back swing of the club, phase 2 is the return of the club to the starting position and phase 3 is the follow through of the club after contact with the ball.

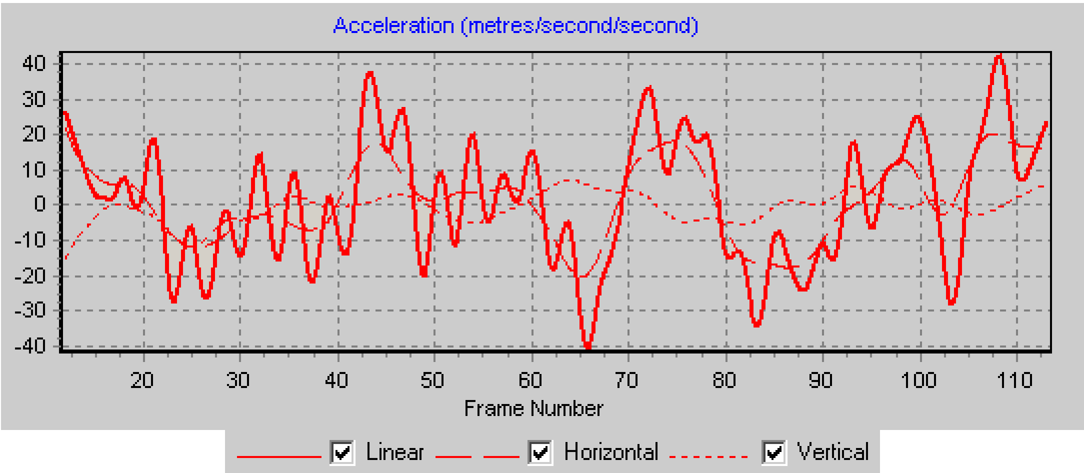
Figure 1: Acceleration of a Golf Club

During phase 1, the initial movement of the club causes a positive linear acceleration. Midway through this phase, the velocity curve changes direction as the club is preparing to slow down approaching the top of the backswing. When the curve changes direction, acceleration is zero. Linear velocity now begins to decrease resulting in deceleration. At the end of phase 1, the club is temporarily static as it changes direction hence no acceleration is occurring. Phase 2 begins from the top of the back swing. The club begins to move in a positive direction towards the ball thus linear acceleration increases positively but as the velocity becomes closer to a constant value, the rate of acceleration slowly begins to decrease. Just before impact, acceleration changes rapidly from $3.38ms^{-2}$ to $-13.28ms^{-2}$, due to a decrease in linear velocity. During phase 3, the club has just hit the ball. There is an initial acceleration during the frame after contact, but then deceleration as the velocity of the club decrease during the follow through.

Horizontal acceleration of the club varies due to the direction in which the club is moving. During phase 1, the initial horizontal acceleration of the club is $-2.37ms^{-2}$. As the club is moving in a negative direction, acceleration is negative. However, as the velocity begins to decrease, the acceleration returns to zero and starts to increase positively. Phase 2 sees the acceleration increasing initially but as the horizontal velocity becomes constant, acceleration decreases returning to zero. As the ball is hit, horizontal velocity of the club decreases resulting in deceleration.

There is little variation in the vertical acceleration of the golf club. During the back swing, vertical velocity increases becoming constant meaning that vertical acceleration, which is initially $0.86ms^{-2}$ returns to zero. As the vertical velocity is on the rise again, vertical acceleration also increases to a value of $0.84ms^{-2}$. By the end of the first phase, vertical velocity has decreased causing the vertical acceleration to increase negatively to $-1.27ms^{-2}$.

Acceleration of the race walker is constantly changing with each step, a step being defined as heel of contact of right foot to subsequent heel contact of left foot. When digitizing the video, the hip was used as the single point of digitisation. Due to acceleration being direction sensitive, a substantial amount of the variation can be accounted for by the continuous change in the hip position, causing an acceleration.



Graph 3: Acceleration of a Race Walker

However, a pattern can be seen in the acceleration for every step. Linear velocity decreases immediately at heel contact and continues to decrease during the first portion of the support period. As the walker extends his other leg in the latter portion of the support period, the velocity increases. Thus, the corresponding acceleration-time graph of a walker during the support phase shows distinct negative and positive accelerations. It can be seen that the walker has higher acceleration values during the second phase of the support period meaning that the walker slows down in the first portion of the support and speeds up in the latter portion. To maintain a constant average velocity, the walker must gain as much speed in the latter portion of the phase as was lost in the first phase.

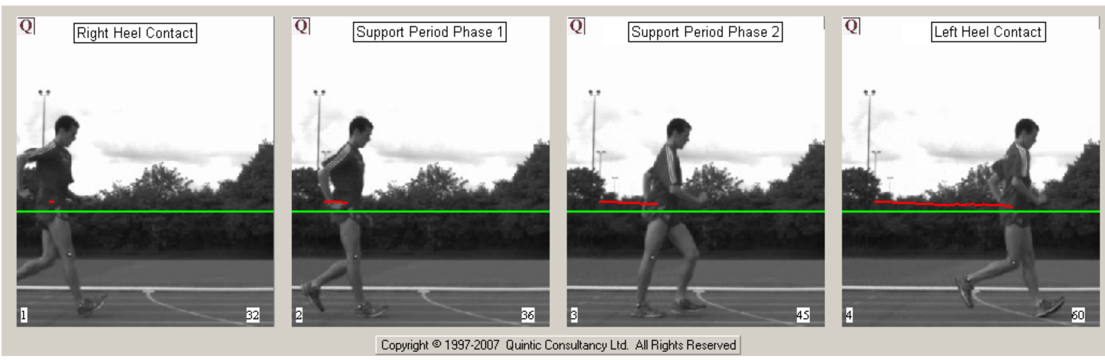
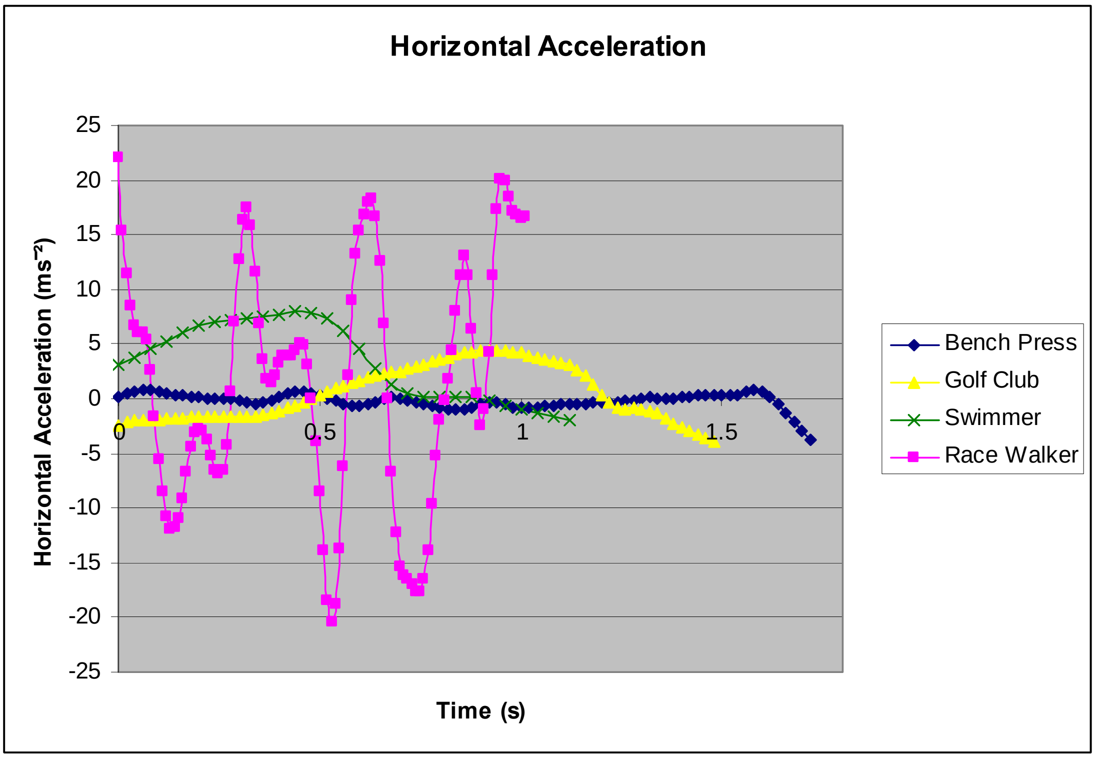


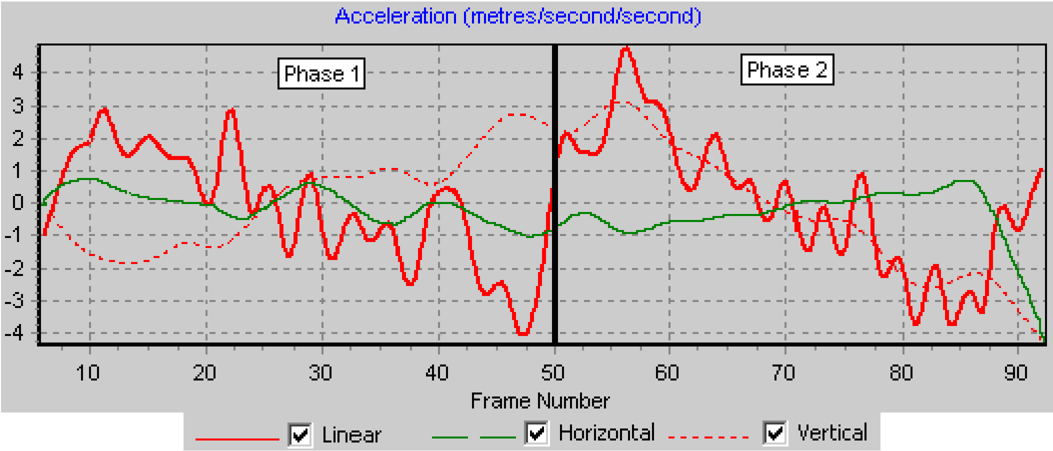
Figure 2: Race Walking Acceleration

Figure 2 demonstrates the changing hip heights of the walker during one step. The green line shows the initial hip height while the red line shows the hip movement during the video. As can be seen from the pictures, as the walker is stepping with his right foot, hip right hip rises above the initial height. Going into the first part of the support phase, and again in the second part, the hip lowers slightly. By the time the left heel makes contact with the ground, the right hip is nearly back to its initial height while the left hip is rising.



Graph 4: Horizontal Acceleration

Horizontal acceleration accounts for the rate of change of velocity along the horizontal axis. The race walker has the most variable acceleration ranging from 20.09ms^{-2} to -22.08ms^{-2}. The swimmer has a steady increase in horizontal acceleration initially but this levels off after 0.76sec at an acceleration of 5.50ms^{-2}, and slowly starts to decrease. This is because once the swimmer leaves the blocks, there are no external forces acting on the swimmer in the horizontal direction and acceleration is zero. As the swimmer enters the water, deceleration occurs. The horizontal acceleration of the golf club is initially negative initially due to the direction of the club from the start of the movement until the top of the backswing. From there, acceleration is positive as the club is now traveling in a positive direction. Once contact is made with the ball, there is deceleration of the golf club. The barbell has the least amount of horizontal acceleration stretching out along the axis with little deviations either side of the axis.



Graph 5: Acceleration during the Bench Press

Graph 5 shows the linear, horizontal and vertical acceleration of the barbell. The horizontal acceleration has been outlined by the green line. This graph has been divided into 2 phases, the first phase is when the arms are being flexed with the barbell is moving towards the chest and the second phase is the extension of the arms while returning of the barbell to its initial position. The horizontal acceleration of the barbell is negligible peaking at -1.01ms^{-2} during the downward phase and -3.78ms^{-2} at the end of the upward phase. The reason for this is that the bench press is mainly an 'up-down' exercise with little movement forward and back. During the first phase of the exercise, horizontal velocity occurs in a positive direction. This is because the athlete is bringing the barbell slightly forward while bringing it towards the chest. This causes the initial horizontal acceleration also to be positive. The direction of the horizontal acceleration is changing constantly as the horizontal velocity is increasing and decreasing throughout this phase. At the end of phase 1, horizontal acceleration is in the negative direction as the horizontal velocity is decreasing in a positive direction. As the exercise moves on to the second phase, horizontal acceleration is negative as the horizontal velocity increases negatively. Once the horizontal velocity becomes constant, horizontal acceleration returns to zero but as the horizontal velocity begins to decrease in a negative direction, horizontal acceleration increases in the positive direction. At the very end of the exercise, the horizontal velocity increases wholly in a negative direction as the barbell is being returned to its initial position. This causes a significant horizontal acceleration in the negative direction.

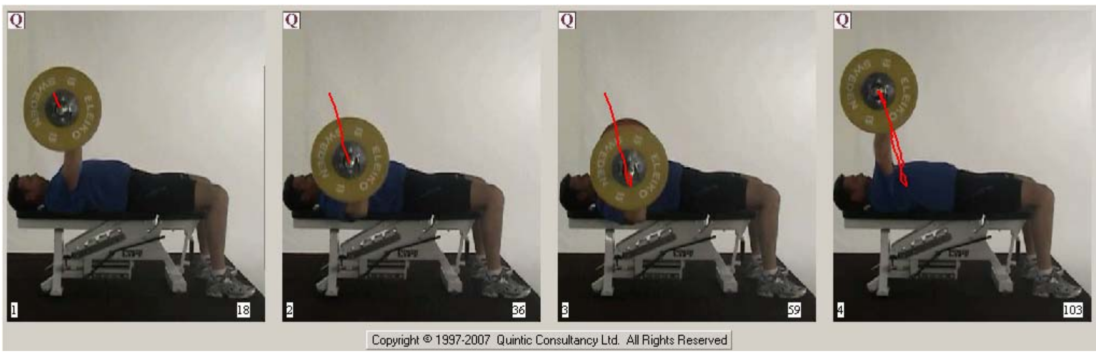
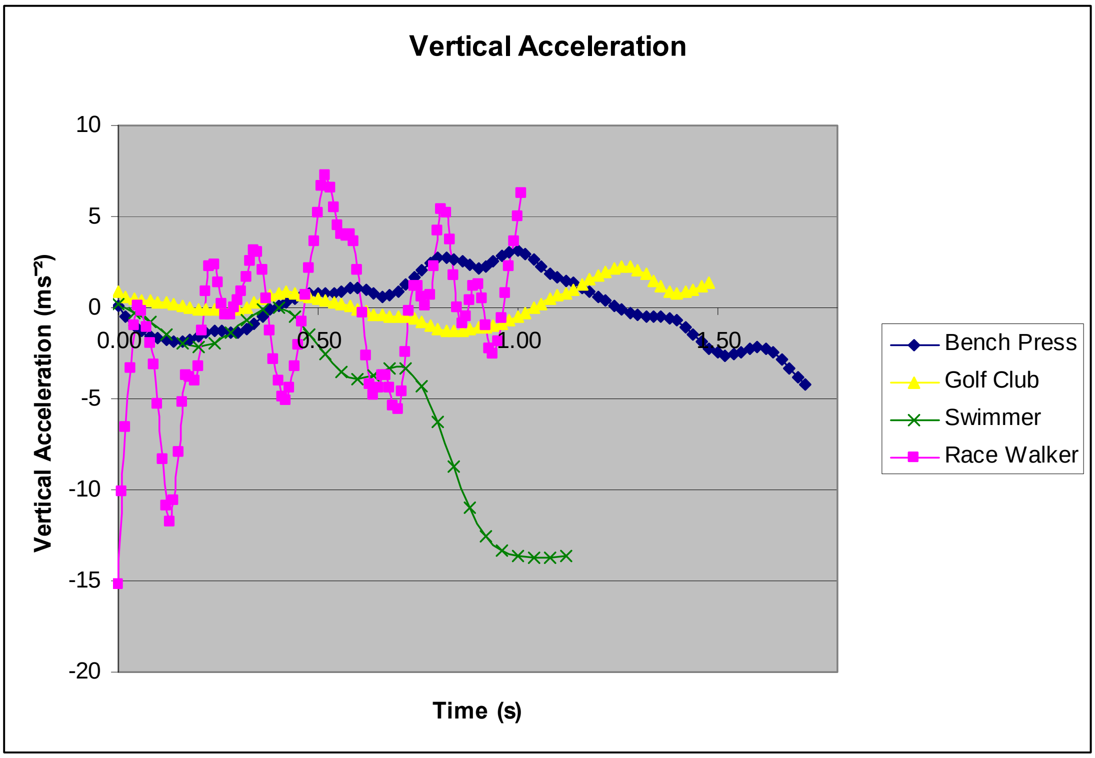
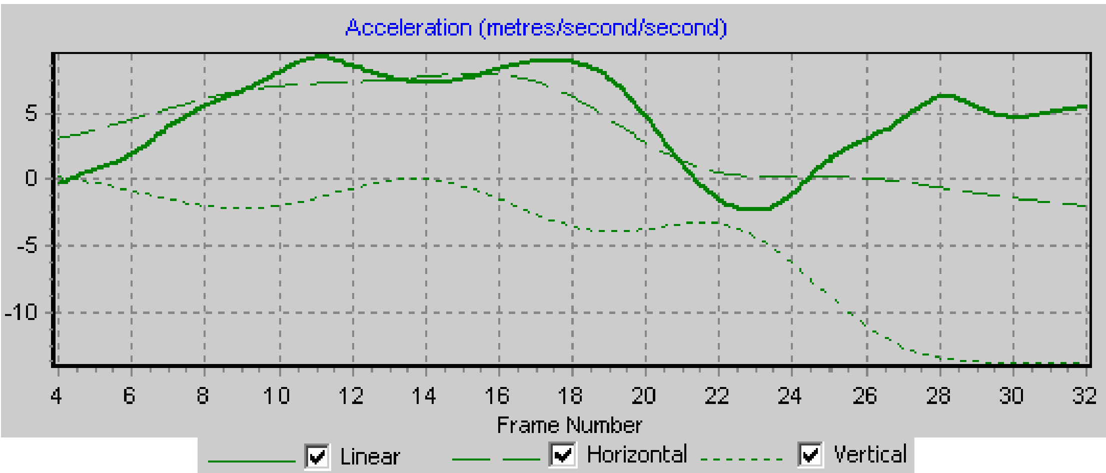


Figure 3: Bench Press



Graph 6: Vertical Acceleration

Vertical acceleration, graph 6, sees similar results to the other graphs. The race walker is the forerunner in highest acceleration with values ranging from -15.23ms^{-2} to 7.22ms^{-2}. The swimmer has a measurable rate of vertical acceleration that is in the opposite direction to the rest, -4.29ms^{-2}. Again, the other skills have negligible vertical accelerations reaching max values at -1.35ms^{-2} and 0.2ms^{-2} for the bench press and golf club respectively.



Graph 7: Acceleration of the Swimmer

Graph 7 shows the acceleration of the swimmer. Initially there is an increase in the horizontal acceleration as the swimmer starts to push forward to leave the blocks. Maximum linear acceleration of 9.16ms^{-2} is reached at this point. As the swimmer comes into the flight stage of the dive, linear velocity becomes constant causing a decrease in the linear acceleration. The final stage of the dive is the swimmer entering the water. Linear velocity increases causing an increase in the linear acceleration during this stage.

Horizontal acceleration of the swimmer increases initially as the swimmer leaves the blocks. This is due to her pushing forward thus positively increasing the horizontal velocity. After 0.76sec, the horizontal velocity becomes constant, hence acceleration returns to zero. At the swimmer has now left the blocks, she has no horizontal forces acting on her thus no acceleration is occurring. Towards the end of the dive, horizontal velocity decreases as the swimmer is entering the water, this causes a slight decrease in the horizontal acceleration in the negative direction.

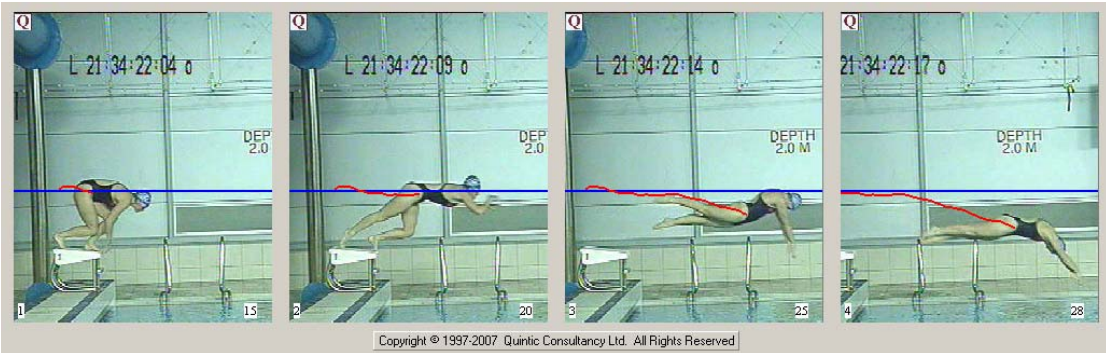


Figure 4: Swimming

Figure 4 shows the different stages of the horizontal acceleration of the swimmer. The blue line represents the initial position of the hip while the red line follows the path of the hip during the dive. Picture 1 is at the start of the dive as the swimmer is starting to push off the blocks. This is where max horizontal acceleration of $7.93ms^{-2}$ is reached. As the swimmer is diving from the blocks, the hip rises slightly as the knees extend. In picture 2, horizontal deceleration is occurring as horizontal velocity is becoming constant. Once the right knee is fully extended, the hip height has returned to just below the original height. The swimmer is about to leave the blocks at this stage. Horizontal acceleration is now zero in picture 3 as velocity is constant. Horizontal acceleration is increasing in the negative direction as velocity is decreasing in the positive direction in picture 4.

Vertical acceleration is negligible for the first 0.52sec while the swimmer is still on the block. Once leaving the blocks, vertical velocity increases in a negative direction causing acceleration in the negative direction also.

Conclusion:

Acceleration plays a major part in all sports. It tells us about all the changes in velocity and in which direction these changes occur. The ability to measure acceleration is a major benefit in majority of athletic sports e.g. running. By measuring the acceleration of a runner, you can calculate how long it takes them to reach their maximum speed i.e. when there is no more acceleration. In doing this you can try to increase the rate of acceleration over a shorter period and hence improve the athletes performance. Nevertheless, you have to be careful when trying to increase an athlete's acceleration. All too often injuries are often caused by changes in acceleration. They can be triggered by decelerating too quickly or a sudden change in direction while maintaining the same speed thus increasing the acceleration. The ACL is a common victim to injury due to acceleration especially in sports such as soccer where a there is a lot of twisting and turning. Finding the optimum acceleration for specific sports is key in enhancing the performance with less risk of injury.