BIOMECHANICS AND ELITE COMPETITIVE SWIMMING

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An emphasis on servicing as opposed to research in the biomechanical support of an elite swim programme results in a quicker improvement of performance. Biomechanics brings to the coach of elite athletes objectivity and quantification with advice from a biomechanical and technical perspective. One important aspect of servicing an elite swimming programme is the development of biomechanical testing systems in which the timeliness of feedback and better accuracy is of paramount importance. Competition analysis provides much relevant information to elite swimming and it also affects a large number of athletes. Once problems are disclosed through competition analysis they need to be addressed in a training environment using biomechanical systems to assist the coach. Biomechanics systems are now available to assist the coach with start, turn, relay change and free swim analysis. Other scientific areas that are being used to advance performance in swimming include active drag, computer modelling and computational fluid dynamics. The A.I.S. is developing a new technology pool which will contain most of this technology and is to be completed by February 2006.

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Having been employed at the Australian Institute of Sport for twenty three years as head of the Biomechanics Department and as a Biomechanist working specifically with the sport of competitive swimming, I would like to relate my experience in these roles with a view to addressing the question of how can biomechanics assist elite swimmers and their coaches.

Servicing or Research to improve performance? Servicing is testing of an athlete or group of athletes which is designed primarily to improve the performance of the athlete or group of athletes being tested. Research on the other hand is athlete testing designed to come up with the answer to a question which has applicability to the performance of the general athlete group that the subjects of the research represent. Servicing aims at directly improving the performance of the athletes being tested while research is designed to develop principles upon which improved performance may be based. Research findings take time to be taken up and applied by the sport. Although research findings have a slower application they have the ability to affect a larger group of athletes.

Pure research and pure servicing lie on opposite extremes of a continuum. In reality, the distinction between research and servicing is not easily defined when the two are close together on that continuum. The servicing of a large number of elite athletes has the capacity to most influence performance of a swim team. For a servicing programme to be effective, the programme must fulfil a number of prerequisites. These prerequisites include: that the testing results in the supply of information which has the capacity to improve performance; an extensive education programme associated with the testing must provide the coach with an understanding of the purpose, the results and how the information is able to be used to improve performance; the testing is carried out quickly and the results are provided in a timely fashion; and that information from the testing is provided in an easily understood format. An organised Biomechanical servicing programme will eventually lead to important questions that are raised by coaches. These questions need to be answered if the servicing programme is to remain effective. Research projects arise as a consequence of the sports biomechanist attempting to answer such questions.

Biomechanics brings to the elite sports programme the ability to provide objectivity and quantification in the measurement of technique evaluation. The biomechanist and coach are then able to apply this information, incorporating knowledge from both biomechanical principles and experience in the sport, to isolate inefficiencies of a technique nature and to propose and develop possible strategies for eradicating such inefficiencies. The sports biomechanist provides the coach with biomechanical advice and the information from biomechanical testing. The biomechanist should not be responsible to guide the athlete technique changes. This is the function of the technique coach or the general coach of the athlete. The biomechanist must however provide the technique coach with advice on changes that need to be made to the athlete's technique, based upon objective results identified from biomechanical testing.

Effective biomechanical testing equipment for a particular sport is not something that can be purchased over the counter or ordered through a catalogue. A major aspect of the biomechanist's role is the development of biomechanical systems that can measure those parameters that best enable an evaluation of the activity under question. For such development to occur the biomechanist must, in conjunction with the coach, decide what aspects of the sport needs to be biomechanically evaluated and what parameters need to be measured to best enable this evaluation. The biomechanist with the R & D technical officer then needs to identify the transducers that will most effectively monitor these parameters and decide upon how best to utilise the transducers in the testing system. If possible, computers with analogue to digital cards, or frame grabber cards if the transducer is a video camera, can be used to collect the signal from the transducers and this will enable a quick capture, processing and display of the parameters being monitored. Effort must also be expended in providing a concise and easily understood format for the interpretation of results. This will readily aid in explaining the results of the Biomechanics testing to the coach.

Certain features of a biomechanical testing system improve its capability as a servicing tool. In a service environment, probably the most important feature of a system is the turn around time taken to provide information from the testing back to the coach. Naturally, there is a trade off between accuracy and the return time of the results from testing. In general, the turn around time for information from kinematic sources is much greater than from kinetic sources. The biomechanist needs to establish the accuracy level required in the servicing environment. In most cases the accuracy level required in servicing is not as great as that required in research. Once the required accuracy is reached by the testing system, the emphasis should be on decreasing the time required to get the information from the system to the coach. Immediate feedback provides the opportunity for a test, retest situation with the coach providing input to the athlete's performance prior to retesting. If the athlete is also able to practise the skill before the retest, this repetitive process provides probably the most ideal approach to skill development. Other beneficial features of a biomechanical testing system are a quick set up and pull down time, the fact that few operators are required for testing and processing of data, automatic rather than operator input into the measurement aspects of the system, and that little interference is caused by the testing environment to the athlete's normal performance. If the output biomechanical parameters from the testing system are superimposed over video footage of the performance, this provides the quantitative biomechanical parameters in conjunction with a recorded image of the performance. The coach is readily able to identify with a video image of performance, making the biomechanical feedback from the system almost self-explanatory for the coach and athlete.

Probably the major aspect that influenced the effectiveness of the AIS Biomechanics support programme in swimming was the introduction of Competition Analysis. While such analysis was reasonably basic, it provided information to many elite swimmers and for this reason influenced the sport in Australia to a large degree. It is only in major competitions that swimmers will produce a maximum effort and this is where an assessment of the swimmer's performance should occur. An analysis of individual swimmer's races at major competitions will provide information concerning each swimmer's weaknesses and their ability to follow their race model in competition. The race analysis information may also lead to a refinement in the swimmer's competition or race model. When the information from the competition analysis is spread sheeted, along with that from other competitors, it is easy for the coach to identify why each race was won and lost. The competition model for a swimmer is the intricate race plan for the swimmer and in this age of high tech international competition it is of paramount importance to performance. It provides not only the split times for the various laps but it also defines how each lap is to be swum. It includes start and turn times as well as the stroke frequencies and stroke lengths that swimmers must maintain throughout the various laps of the race. Competition analysis also reveals a swimmer's weaknesses that then should receive special treatment in the training programme. Competition analysis also enables statistical analysis on the data to identify new trends in competition swimming, as well as the affect of rule change on performance. Studies by Jodi COSSOR and myself from the competition analysis at the Sydney Olympic Games revealed that swimmers who travelled further under the water in starts and turns in the form strokes performed significantly better in these aspects of competition than those who did not travel as far.

When we perform competition analysis at major swimming meets in Australia we utilise many analysers in the project. This has the effect of bringing university students of human movement into an environment where they are working with the elite sport. This exposes a large number of potential sport scientists to an experience in sports biomechanics and swimming. Some of the information obtained through race analysis includes data concerning: starts, turns and finish times, split 25m times, stroke lengths, stroke frequencies, velocities and efficiency indices for the free swimming phases in each event. The A.I.S. analysis system is also capable of identifying important parameters within starts and within turns. Information from the competition analysis is distributed around Australia. This has the effect of providing performance information about Australia's top athletes to the elite swimming centres around the nation. This in turn provides performance based information to the pool of emerging talent that is able to be used as a base in constructing a competition model for these developing swimmers. The competition analysis system that AIS Biomechanics uses for major swimming competitions on home soil involves much equipment and a large number of individuals in teams to process the information.

During smaller meets within Australia and when travelling with teams to overseas competitions, a single operator analysis system called SWAN is used. The limitation of SWAN is that for each SWAN system only a single swimmer can be analysed in a race. The operator needs to be skilled at using the SWAN system to obtain reliable results. The advantage of the SWAN system is that the results are available immediately following the race together with footage of the swimmer's performance. The analysis of the swimmer's performance is processed as the race progresses. As well as provide the competition analysis information on a printed sheet this information is also overlayed on the video image of the swimmers performance which is available on pool deck in real time.

When weaknesses are identified by competition analysis in the performance of a swimmer, these weaknesses need to be addressed by the swimmer's coach if the swimmer is to remain competitive in international competition. To assist in this process the SWAN system in another mode is also capable of analysing, starts, turns, relay changeovers and free swimming technique in a training environment. As well as break down each of these skills into phases, an underwater video in which the camera moves along with the swimmer is provided to assist the coach. Timing information about the breakdown of the swimming skills of the swimmer is provided to the coach with comparative data derived from Australia's elite swimmers so that the coach is able to easily identify problem areas. Such analysis is frequently requested by the A.I.S. swim coaches in Canberra.

At the AIS, the biomechanics department developed an instrumented starting block to examine swim start technique. As a force platform was incorporated into the block, the system was able to monitor the vertical and propulsive force pattern exerted by the swimmer on the block before and after the start signal. First movement time, the force pattern including the grab force developed by the athlete against the block, the time taken to leave the block, the horizontal and vertical velocity off the block and hence the angle of takeoff (movement direction of the swimmer's C of G at the moment of leaving the block), the average acceleration off the block and the power produced are all reported. The output of this part of the biomechanical testing system is produced in the form of a graph and printout that is available within a minute of the start being performed. The equipment is based around a kinetic transducer system, linked to an analogue to digital card in a computer. The SWAN start analysis is conducted in conjunction with the instrumented block to provide further information about the starting performance to the 15m mark. As well as a printout of the overall start performance it provides both an underwater and an above water video image of the performance that may be reviewed by swimmer and coach immediately following the performance. A magnetic timing system is used to provide accurate timing of the head to the 5m, 10m and 15m distances out from the block. An underwater camera tracks the swimmer out from the wall to provide video footage of the performance. An example of some of the information produced by this equipment on one of the AIS Female freestyle sprinters is provided. Start Time (criteria performance measure - head to 15 m) = 6.69 sec, First movement time (after start signal) = 0.12 sec, Time to leave Block = 0.80 sec, Horizontal velocity on leaving the block = 4.80 m/s, Angle of C of G movement on leaving block = 18.0 deg downward, Average forward acceleration off the block = 6.05 m/s/s, Average power developed on block per Kgm of BWt = 19.35 watts, Horzizontal flight distance (leave block to head in water) = 1.1 m, Resurface distance = 9.7 m, Resurface time = 3.96, Underwater average velocity = 2.42 m/s, Time to 5 m = 1.59 sec and Time to 10 m = 4.16 sec.

The biomechanics department has also developed an instrumented turning wall to examine swim turn technique. As a force platform was incorporated into the wall, the system is able to monitor the force pattern exerted by the swimmer on the wall during the turn. The horizontal propulsive, vertical and lateral forces of the swimmer's action against the wall are monitored and hence the change in angle of movement off the wall, the change in forward velocity, the average forward acceleration and the power produced on the wall are all reported. The output of this part of the biomechanical testing system is produced in the form of a graph and printout that is available within minutes of the turn being performed. The equipment is based around a kinetic transducer system, linked to an analogue to digital card in a computer. The SWAN turn analysis is performed in conjunction with the instrumented turn wall to provide further information about performance in and out to the 7.5m mark. As well as a printout of the overall turn performance, it provides both an underwater and above water video image of the performance that may be reviewed by swimmer and coach immediately following the performance. A magnetic timing gate system is used to provide accurate timing of the head from and to the 5m, 7.5m and 10m distances out from the wall. An underwater camera tracks the swimmer in and out from the wall to provide video footage of the performance. An example of some of the information produced by this equipment on one of the AIS Female freestyle sprinters is provided. The criterion measure for turn performance, which is the time taken for the head to travel from 7.5 m on the way in to 7.5 m on the way out was 7.94 sec (1.89 m/s). This was comprised of a pre-rotation phase (1.71 m/s); a rotation period of 0.78 sec; a push off period of 0.41 sec; and an underwater phase of 2.50 sec (2.08 m/s) with breakout at 6.90 m from wall. The timing that the swimmer's head reached the 5 m distance after initial foot contact with the wall was 1.93 sec, for 7.5 m was 3.42 sec and for 10 m was 4.90 sec. The pre turn swim velocity was 1.60 m/s and the post turn was 1.76 m/s. The instrumented force wall indicated that 0.41 sec was spent on the wall, that maximum perpendicular force was 1.85 BWt at 0.20 sec after contact, that the centre of push off pressure was 16.6 cm below the water surface, that foot contact resulted in a change in perpendicular velocity of 3.66 m/s, that the average perpendicular acceleration off the wall was 9.02 m/s/s and the perpendicular power expended during contact was 16.42 watts per Kgm of BWt.

The free swim SWAN analysis consists of filming the swimmer performing between magnetic timing gates while at the same time monitoring the stroke timing of the swimmer. This provides information about stroke frequency, stroke length, swim velocity and a measure of swim efficiency. The A.I.S. is presently developing a system to monitor the pressure change between the front and back of the hand throughout the stroke, in conjunction with the extent and timing of hip and shoulder roll as the swimmer performs through the swim internal between magnetic gates. At present such information is logged on board the Traqua device and in post processing linked with the video image. The purpose of this system is to provide useful information about the functional symmetry of propulsion in both hands during the swimming stroke cycle. At present we are working toward linking this information by way of an above/below water telemetry system with the computer that stores the video image from the underwater camera. This will enable the extent and timing of both hand pressure and body roll in graphical format to be superimposed over underwater video footage of the swimmer's performance in real time.

Another area in which AIS Biomechanics is working to enhance swim performance is the measurement of active drag in swimmers. Active drag analysis when measured accurately may be used as a means to objectively assess free swimming efficiency. This is on the basis that one of the two major aspects that affect free swimming velocity is the ability to streamline and to reduce drag. The evaluation of active drag can be assessed by two different methods. The first involves having the swimmer perform at maximum speed and measure the swim velocity. The swim is again performed at the same intensity as the first, but a retardation force is applied to the swimmer. The force applied should be no more than to slow the swimmer by up to approximately five percent. Both the retardation force and the swim velocity are measured and both are applied to the cubic equation to compute active drag. This procedure can then be repeated using an assisting force in place of the retardation force to perform a similar operation to check the measure of active drag. The major control in this testing is that the same intensity should be applied to all swims. As a cubic equation is involved in the calculation of active drag any small inaccuracies in measurement or in the maximum consistent effort put forward by the swimmer may result in large variations in the measure of active drag. Another important factor to obtain reliable measurements for active drag is to ensure that the swimmer performs all trials with an identical technique.

Professor Huub Toussaint in the Netherlands was heavily involved in the design of the MAD system. The MAD system consists of a long metal tube that is located under the water in a pool along the lane. The metal tube has upward directed handles that the swimmer uses to pull and push upon and propel themself in a freestyle swimming type action. The horizontal tube is connected to a force transducer at the end of the lane. The force required for the swimmer to travel at a set speed using the simulated front crawl motion can be measured by the transducer as representing active drag. The MAD system is also able to provide the coach with a measure of energy usage for the swimmer to perform at set speeds.

The A.I.S. has developed a system where a swimmer is filmed with 3 pairs of cameras (a pair of cameras consists of one above and one below water level). Through manual digitising and in conjunction with the DLT algorithm the A.I.S. has been able to develop a 3D skeletal model of the swimming performance that represents the technique of the particular swimmer who was filmed. Representing the technique utilised by a swimmer by recording the movement of the swimmer's joint centres throughout the stroke, in terms of 3D spatial coordinates, enables a biomechanical model of performance to be the archived. The skeletal image representing the swimmer's technique is then able to be viewed from any direction. The three dimensional model of swimmers can be readily used by visual inspection by the coach in two major areas. When the swimmer's performance goes through a slump, the modelling may be used to identify changes that have occurred in the swimmer's movement patterns and their timing. Modelling may also be used to quantifiably compare the technique of two swimmers who have never actually swum together.

The A.I.S. is building a new pool in which the Skill Technology magnetic analysis system may be used to obtain such performance information about a swimmer. The process of obtaining the spatial 3D coordinate information to replicate a swimmer's technique with a skeletal model will be able to be collected simply and quickly. This will enable the technique of many elite swimmers to be stored in a scientific form and used for comparative studies.

Research work by Barry Bixler from the USA in the area of computational fluid dynamics has been used successfully in the design of the new swim suits. Andrew Lyttle from Australia has also successfully employed CFD to analyse in a research project the different kicking patterns and the affect on propulsion of underwater dolphin kicking in starts and turns. The A.I.S. is in the process of taking on a three year Ph.D. scholarship in conjunction with an Australian university and the Australian national scientific research organisation to study how CFD may be used in the betterment of performance in swimming. It is hope that this research area in conjunction with the skeletal modelling proposed above and body scanning may be useful to refine a particular swimmer's technique. Here the technique of a swimmer will be captured to enable the performance to be reviewed by the coach and biomechanist. Changes that are proposed can be altered in the model and tested and tuned using CFD methods prior to actually changing the swimmer's motor programme.

At present much of the servicing of swimming at the A.I.S. is limited by the time taken to set up, calibrate and dismantle the testing equipment. In the future this problem will be practically eliminated with the construction of a new technology pool. The pool itself will be a 50m by ten lane Olympic size pool with a constant 3 m depth. It will only be used for scientific research and servicing as well as for national swim team and A.I.S. swim team training sessions. There are to be no competition facilities built into the pool so as not to cause any distraction from its true purpose. The pool is presently being built and is expected to be operational by February, 2006. The unique feature of the new pool is the scientific instrumentation that is to be built into the pool. No longer will biomechanists have to spend hours of their timing setting up and calibrating equipment. I will attempt to list some of the features that are to be incorporated into the new pool.

1. Instrumented Starting Blocks (Coach & Biomechanics)
2. Instrumented Wall (Biomechanics)
3. Side Pool Deck Filming Trolley (Biomechanics)
4. Underwater Moby Cam (Biomechanics & Coach)
5. Pacing Lights (Biomechanics & Coach)
6. Digital displays and Camera in porthole below blocks (Coach)
7. Magnetic Timing System (Biomechanics)
8. Filming vehicle from above (Coach & Biomechanics)
9. Fixed wall cameras for Competition analysis (Biomechanics)
10. Video Control Room (Coach & Biomechanics)
11. Pool's Timing system, scoreboard and AEO Room (Biomechanics & Coach)
12. Distance Markings in the pool floor (Coach)
13. Transmission of signals to swimmers in pool (Coach)
14. Biomechanics Storage room (Biomechanics)
15. Competition analysis collection room {in Video Control Room?} (Biomechanics)
16. Skills Technologies 3D System (Biomechanics & Physiotherapy)
17. Active drag measurement by servo control device (Biomechanics)
18. Active drag measurement by MAD system (Biomechanics & Physiology)
19. Overhead Tow Equipment (Coach)

We live in a world in which technology affects every aspect of our lives to a greater extent every year. Competitive swimming will more and more seek the advantages of using scientific equipment and procedures to make advancements in the sport.