On-field movement patterns: a report on the 2004-06 GPS project for Touch Football Australia

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Executive summary

This paper discusses the 2004-06 GPS project involving collection and brief collation of data recorded on players and referees in competitive game situations. The discussion involves the type and nature of on-field movement and briefly discusses training programs that are currently in use and looks at some possible alternatives.

The document briefly discusses the sport's involvement in an earlier project, looks at the purpose of the research and describes the equipment used in the project, specifies the acquisition methodology, summarises data and then briefly discusses the results. A number of conclusions result and recommendations for further actions are made.

Movement patterns – background

In 1983 an innovative research project (Allan Report) was brokered by the author through the (then) Darling Downs Institute of Advanced Education in Toowoomba. That project aimed to ascertain movement patterns of different players in the sport of Touch. The objective was to identify energy requirements for the game and subsequently design appropriate training programs, quite a new approach to sport and associated training. That project involved marking a field by using white powder with five-metre grids and during the conduct of a game using seven video cameras mounted on small superstructures. The manually operated cameras acquired individual movements of three players from each team as well as the single referee (seven manually operated cameras). Subsequent, rather complex and tedious, manual analysis of the video footage resulted in valuable, preliminary data concerning on-field movement patterns of players and of the referee. Analysis of positional movement was based on individual and personal assessment from the video footage, spooling slowly through each tape and manually estimating direction, speed and distances covered, followed by detailed recording of that data.

The recording and analysis project took almost a year to complete and several important outcomes resulted. The longest sprint recorded was a little over sixteen metres. It was established that a significant element of the game was spent at very low speeds. No heart rate data was recorded. The (then sole) referee travelled further than any of the recorded players. As a result of this project dual refereeing was introduced and some more-specific training programs were developed for the sport.

The game has changed considerably since the Allan project. No longer are markers allowed and the number of on-field players has reduced from seven to six. The style of play has varied somewhat and the game speed and intensity has increased, primarily due to the evolution of the running dump, previously the static rollball. Additionally, most (certainly in the representative arena) matches are now adjudicated by a team of three referees.

The need for current, sport specific technical movement data had been identified and discussed for some time and in early 2004 the author and the (then) Assistant Executive Director of (the then) ATA undertook some investigations to identify possible, innovative systems that would allow accurate, economical and most importantly simple and practical data recording of on-field movement patterns for both players and referees. In March of that year, following appropriate testing of various systems, a transfer of quotations and transaction negotiation, justification submissions and approvals, the (then) ATA procured a number of GPS recording systems and software from GPSports, a Canberra-based sports research company.

GPS stands for Global Positioning Systems and the positioning principle involves tracking of earthly movement on land, sea or in the air using communications between an 'earthly' located recording unit and any or some of the more-than-twenty specific GPS communication satellites that are currently in Earth orbit. To track an object, there is a need to attach a recording unit to that object and data can be transferred between that unit and the communications satellites. This project employed the systems in tracking individual players and referees as they moved on and around the playing field during the conduct of Touch matches.

Purpose of project

There were two prime reasons for undertaking the GPS tracking project:

- Perhaps the most important objective was to identify accurate player / referee movement patterns on which scientifically-based training programs could be developed. Because of the reducing gap between Australia and other international competitors at the elite level, it became apparent that everything possible needed to be done to remain Number 1. Scientifically based training programs were needed.
- No purposeful recording of player / referee movement patterns had been completed for more than twenty years. The data acquired in 1983 needed to be tested for validity in the modern game. Anecdotal evidence and discussion amongst elite players and coaches indicated that the twenty-year old data may have been out-of-date and irrelevant to the modern game.

Valid movement data would also enable analysis of the fitness (energy) requirements and development of appropriate training regimes that would allow representative and elite players and referees to achieve and maintain peak physical performance. Other project issues were considered including the following matters, however it was decided to proceed and expand on such matters as and when necessary:

- Resource requirements, especially data collection, storing and collation, and any associated training of operators / analysts as required
- Privacy matters, especially for those involved in data provision, and especially if the data related to younger people, where parental permissions would be necessary

- Safety issues, especially regarding heart rate issues for mature players
- The possibility of further questions on the game being posed, requiring additional or specialist research and the potential for further project requirements
- Distribution and confidentiality of the project outcomes

Recording equipment

The recording system needed to be lightweight, simple to use and easy to attach to individuals, and of course safe for use in normal competition activities that included evading, firm contact, diving and rolling that may occur during a game. Because it was considered vital to the project that data from representative games was recorded, there was a need to reduce or remove any hindrance to all players and / or referees to ensure the recording equipment did not interfere with their physical (and / or competitive) performance and at the same time providing accurate data.

Most individuals who wore the equipment commented that after a short period they actually forgot about the equipment and it had little or no effect on their performance. A small handful of players removed the equipment part-way through acquisition due to perceived interference or slippage of attachments. A couple of players commented that they were happy to wear the unit because they were aware someone was watching them and that made them work a little harder. Several players refused to wear the equipment on the advice of their coaches.

The GPS recording system used for this project consists of a number of hardware pieces and some software. The hardware includes:

- The remote recording unit, which is a small yellow piece with a clear LCD face, about the size of a standard mobile phone, with dimensions 11cm by 5.0cm by 3cm and weighing only approximately 110gm, the SPI10 is one of the world's most advanced sport GPS products. Controls include appropriate data recording (i.e. start / stop / download) and other operational and setting aspects. Each remote was capable of recording up to 3 forty-five-minute sessions.
- A lightweight harness and pouch for attaching the remote to the upper back area of the player / referee. The harness wrapped around each of the shoulders and was connected and secured with strips of Velcro.
- A chest strap transmitter that is based on standard heart rate transmission protocols. The unit transmits heart rate data up to 1m from the SPI10.
- A battery charger adapter to connect the remote to a power outlet for recharging.
- A computer interface cable, allowing the unit to be connected directly to a computer through either a serial or a USB adapter.
- A fabric case to house and carry the above pieces.

The SPI10™ technology involves a 1 Hertz GPS chip (data collection once per second). New updates will include a once every 2, 5 & 10 second data collection rate & increased logging time (to 4+ hours). There is potential for software upgrades to the

SPI10™ allowing the user to upload new software programs, and the ability to be able to link in peripheral devices such as cadence & stroke rate.

Some simple illustrations of the recording equipment are shown below:

The main remote recording unit - GPSports SPI10

The harness and pouch

The heart rate monitor / transmitter chest strap

Software

The GPS analyser software program is a Microsoft Windows based product that can capture the data stored by the SPI 10 allowing the user to:

- Store multiple sessions (up to three games of data)
- View speed and heart rate performance throughout the entire session
- View the actual movement path taken during the session
- Generate multiple graphs and reports (significantly configurable)
- Instantly determine the total time and distance spent in different Speed Zones
- Instantly determine the total time spent in different Heart Rate zones
- Develop detailed comparison data - athlete to athlete, session to session
- Produce a second-by-second review of physical movement performance

Graphical outcomes – software

Three main elements are briefly described below:

The Analyser Graph (see Figure 1, below) page gives an unedited view of performance of the athlete. The viewer can see what speed the athlete was at each second for the entire performance. This is an important colour-coded, graphical representation of the participant's physical performance during the game. The following image is an actual performance recorded at the Australian 18s Championships. The red background is representative of heart rate while the light blue images represent player speed.

It should be noted that the game is represented as two halves, with the player performing (on-field) for six times in the first half and again six times in the second half. Note that the times off the field are about equal to on-field time (1-for-1 sub). It is of particular interest to note the player's indicated heart recovery rate (in the sub box) relative steepness angle after each on-field session. Note that the heart rate did not recover fully prior to half-time due to insufficient rest periods and that the player's heart rate spikes during the (recovery) half-time period at 04:27. The particular player was the team captain and spoke at that time. It is also noted that his top speed recorded during the game was just under 26 KPH (and that player has a peak raw speed ability of just on 31 KPH).

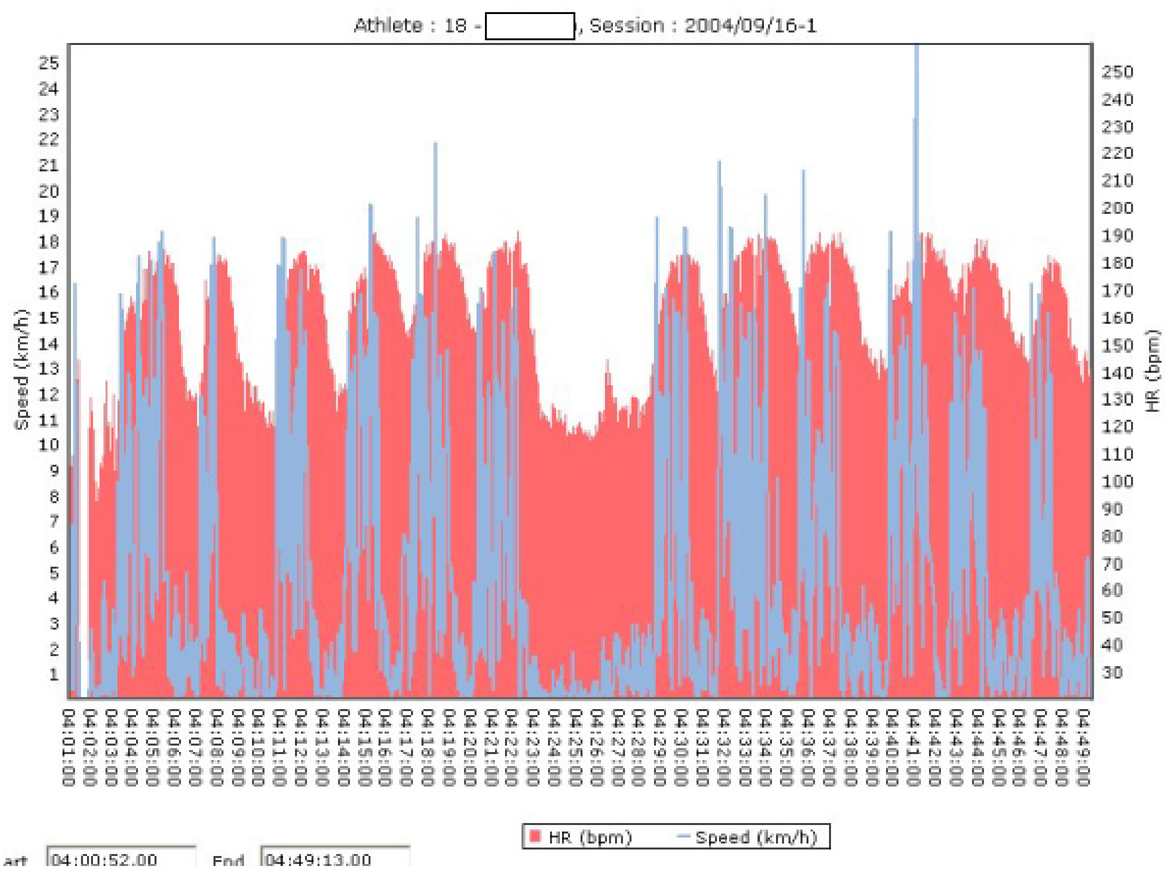


Figure 1: Analyser Graph (Player's Name blocked out)

The Analyser Map allows the user to view their actual path taken during their exercise/competitive performance, based on a once-per-second reading. This aspect shows colour-coded speeds and selected colour-coded heart rates for the duration of the activity.

In the example shown (Figure 2, below) the grid lines are 10 metres apart and the field alignment is slightly clockwise with the sub box obvious. The colour coded tracks indicate the player's actual speed (yellow below 7 KPH, dark blue 7 to 12 KPH, etc) The software allows users to remove one or more speed zones to more accurately analyse a particular zone.

From a simple analysis of this map it could be assumed that the subject was a middle player. Note the light blue at the lower end of the sub box. As light blue represents 20-25 KPH, this indicates a fast interchange. It was noted that in numerous instances, both for males and females of all ages, the fastest actual speed recorded by a player in a game was during the interchange procedure.

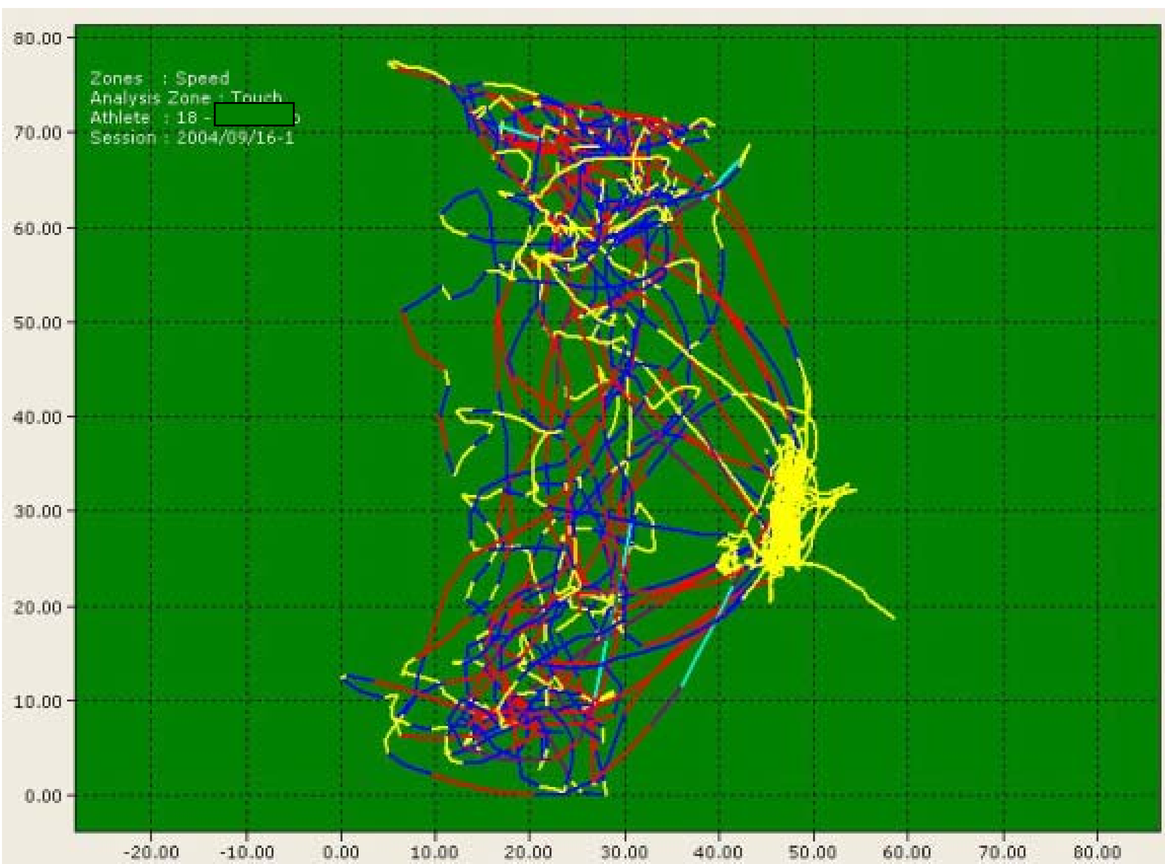
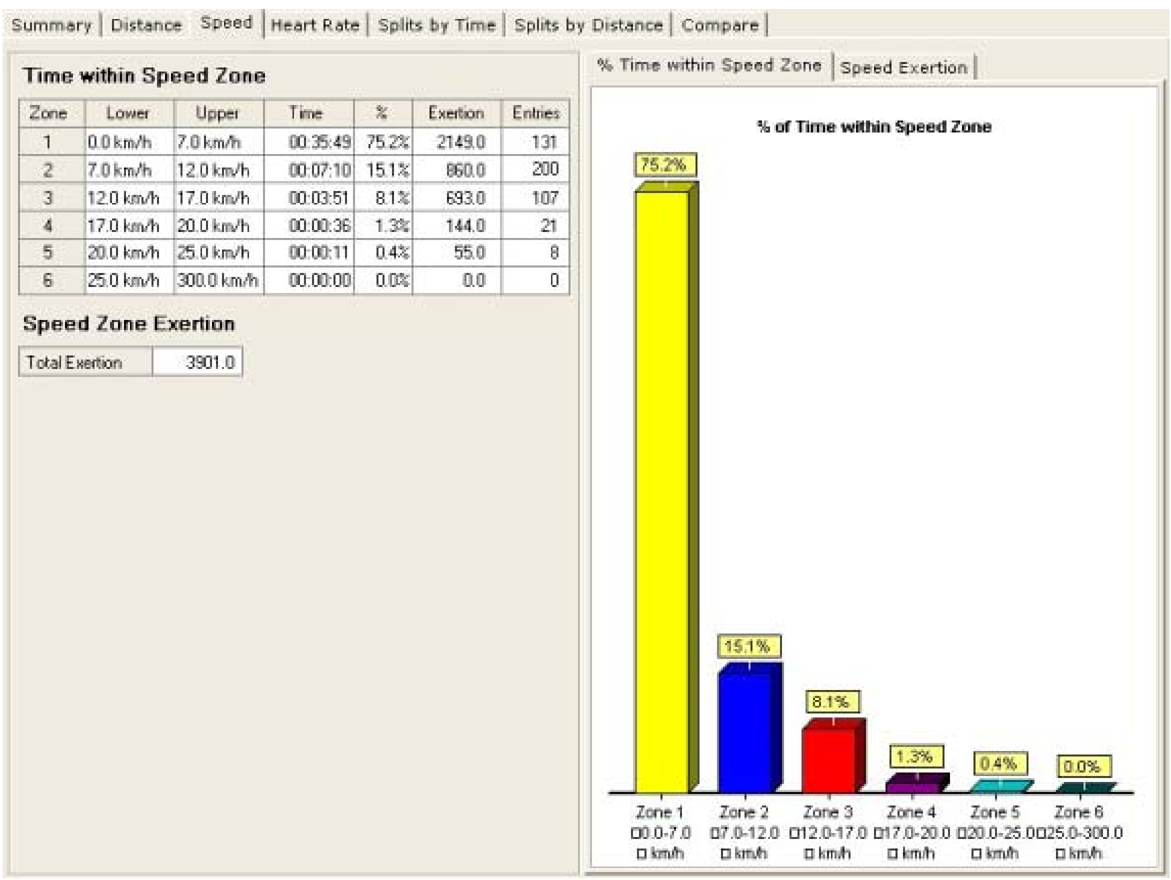


Figure 2: Analyser Map (Player's Name blocked out)

The Analyser Splits window (Figure 3, below, for the same player) allows the user to split the session into time or distance segments. The software supplies distance & minimum, maximum and average speeds for each time segment. This element also allows analysis of time spent in a specific Heart Rate Zone or Speed Zone. The top bar menu provides some indication of available data analysis.

In the example shown the subject spent 75.2% of the total duration of the game in speed zone 1 (less than 7 KPH), and it is noted later that this is on the lower scale of average for all players (just under 80% of the game at less than 7 KPH). The speed zone spit for this subject is shown in the table on the upper left of the image. Note that the player did not spend any time zone six (over 25 KPH) and only spent 0.4% of the game duration in zone five (20-25 KPH). This has been noted to be on four short and separate occasions, once related to an interchange.

Of interest to future projects is the percentage spent in the mid-range zones, two, three and four. This aspect will have an important influence on future training programs.



Zone	Lower	Upper	Time	%	Exertion	Entries
1	0.0 km/h	7.0 km/h	00:35:49	75.2%	2149.0	131
2	7.0 km/h	12.0 km/h	00:07:10	15.1%	860.0	200
3	12.0 km/h	17.0 km/h	00:03:51	8.1%	693.0	107
4	17.0 km/h	20.0 km/h	00:00:36	1.3%	144.0	21
5	20.0 km/h	25.0 km/h	00:00:11	0.4%	55.0	8
6	25.0 km/h	300.0 km/h	00:00:00	0.0%	0.0	0

Figure 3: Analyser Splits

Other imagery and data are available but not discussed here.

Measurement zones

As we were one of the initial Australian and International users of the package, the software had not been used or calibrated for any similar field sports. Formerly it had only been used by individual athletes in sports such as skiing, cycling and distance running. There were two major software elements that needed specific sport factoring or calibration to allow data to be reasonably interpreted:

1. Speed Zones. The software was designed to breakdown the recorded speed of tracked individuals into specified Speed Zones. The system was set up to record speeds from zero three hundred kilometres per hour. To enable the software to function in a practical sense, dividing player / referee data into specific levels, there was a requirement to allocate six Speed Zones that were applicable to the game. Based on personal background, technical knowledge of the game, involvement in former (tertiary and post-tertiary) research projects together with a dash of common sense, the Speed Zones were set-up by the author as follows:
   - Zone 1: From zero up to 7 kilometres per hour (KPH)
   - Zone 2: Over 7 KPH and up to 12 KPH
   - Zone 3: Over 12 KPH and up to 17 KPH
   - Zone 4: Over 17 KPH and up to 20 KPH
   - Zone 5: Over 20 KPH and up to 25 KPH
   - Zone 6: Over 25 KPH

2. Heart Rate Zones. Similarly to the Speed Zones, the software incorporated up to six Heart Rate Zones. Breaking down the levels into specific zones was a difficult decision primarily because the intended data was to be directed at players and referees of ages varying from teenagers up to seniors aged over 45 years. Heart rates during physical activity vary considerably with age, and also with gender however it was decided to place a bias towards younger, open level players. The six Heart Rate Zones were established as follows:
   - Zone 1: From 0 beats per minute (BPM) up to 120 BPM
   - Zone 2: Over 120 BPM and up to 140 BPM
   - Zone 3: Over 140 BPM and up to 160 BPM
   - Zone 4: Over 160 BPM and up to 180 BPM
   - Zone 5: Over 180 BPM and up to 200 BPM
   - Zone 6: Over 200 BPM

Data limitations

Initially participant age and gender were recorded. However as the project developed, resources were limited and time constraints applied, these variables and also the participant playing position and other issues had to be ignored. Thus the same Speed Zones and Heart Rate zones were used for the analysis of data from male and female players of all ages, and also for male and female referees of all ages. This generalisation obviously will have some influence on preliminary outcomes. For future recording and analysis, player and referee age and gender should be recorded, together with more detailed individual aspects.

Data collection methodology

The collection process involved a number of steps that were established, tested, reviewed and developed during the initial recording periods. The remote SPI10 unit was capable of recording about three games of data on a single battery power and it was necessary to download and clear acquired data and then recharge the internal battery after that time. The remote recording units were connected to a standard power outlet with the battery adapter lead. A complete battery charge took about two hours. Units were left on charge overnight and scheduled for re-charging between down-times in tournaments when not in use.

During the first year of acquisition, the focus of data collection was directed mutually towards both players and referees. When a suitable team (division, age or gender) was identified, the team coach was approached and asked if there was any player interested in having the unit fitted for data recording. Initially the request was for a player who would be 'working a bit'. Most agreed and selected / nominated a player, usually one of the more experienced or supposedly 'fitter' athletes. Some coaches declined as they believed the unit would distract a player's attention from the game, especially when the game was important to the tournament outcome. All coach decisions were respected however, as teams and the general tournament community became aware of existence of the units, and in particular the capability of what it could quickly provide, fewer approaches were declined. Players were more than willing to wear the units and get feedback on their performance.

Whenever possible harnessed were fitted during the warm-up period to allow players to become more familiar with the harness. Few adjustments were required after the initial fitting. Players and coaches were briefed on what the unit would do and thus the purpose of the project was provided some promotion. Players and coaches were always invited to view downloaded data at the completion of the game and most sought that feedback. Indeed, several players noted performance improvement based on improved interchange procedure graphically represented in feedback sessions.

Initially, during the first few days of acquisition, no urgency was given to approaching players fitted for analysis and halting data acquisition post-competition. However as it became obvious that game statistics were dependent on accurate game duration, players were then approached immediately after the final siren and data recording concluded as quickly as possible. Total duration of recording time thus reduced from a less-then-reliant 50 minutes or so to a more accurate 45-47 minutes. Data was normally downloaded to a laptop computer immediately following a game.

For data collection of referees, it was a matter of approaching their coordinators and explaining the required process. Referees were very keen to review their post-game performances and make comparisons regarding recorded data.

Data summary: players

The following summarises the data collected during the period March 2004 to November 2006, at the following tournaments:

- NTL 2004, 2005, 2006 (Open and Seniors)

- Australian 18s Championships 2004, 2005, 2006
- State of Origin 2006
- Defence National Championships 2004, 2005, 2006
- Australia Cup 2004, 2005

There were some game recordings that were not used because:

- Data was not recorded for a complete game
- Data was recorded for much longer than a complete game
- Data became corrupted or was otherwise misplaced

The following statistical player data was collated and considered worthy of report:

Total number of recordings:	Open – 82, Senior – 66
Spread of (known) player ages:	Youngest – 17, Oldest – 49
Average distance travelled in a game:	Open – 3,120 m, Senior – 2,960 m
Longest distance travelled in a game:	Male – 4,400m, Female – 4,100m
Average speed throughout a game:	Open – 4.51 KPH, Senior – 4.88 KPH
Average % of distance at or below 7KPH:	Open – 89.24%, Senior – 73.23%
Fastest speed recorded:	Open – 32.0 KPH, Senior – 31.7 KPH
Average % of time in Speed Zone 2 (7-12):	Open – 6.86%, Senior – 17.26%
Average percentage of time in acceleration:	Open – 42%, Senior – 43%
Average percentage of distance accelerating:	Open – 53%, Senior – 53%
Heart Rate in Speed Zone 1:	Open – 64% Z5, Senior – 16% Z5
Highest Heart Rate recorded:	Open – 210 BPM, Senior – 211 BPM

Perhaps the most interesting difference between open and senior players was the comparison between heart rates when time was spent in speed zone 1 (i.e. at or below 7 KPH). For open players, that figure was 64.47% while for senior players the figure was a very different 16.53%. This was seen to be due to two causes:

- Younger players are more excitable and are even coached to 'get and keep involved', even when in the sub box where they are supposed to be recovering.
- Senior players are more relaxed and have a fairly even spread of Heart Rate readings across each Speed Zone.

This result should question the technique of getting players 'involved' and keeping them that way. It is proven and acknowledged that a certain degree of anxiety and arousal is necessary for peak physical performance. However as research also proves and is acknowledged, too much excitement results in reduced performance. Additionally, there is a finite amount of heartbeats available for any one competitive performance and it can be expected that energy reserves will be required towards the end of a game. Therefore if heartbeats are 'used up' while players are supposed to be recovering, the likelihood of physical fatigue and the resultant lesser quality performance towards the latter part of the game are increased.

Perhaps coaches should look at using the time in substitution for what it can provide, principally physical recovery? This does not ignore the opportunity to discuss skills, tactics or individual performances with players but it does lead towards the need for a formal and research-based process in the sub box.

The other interesting result was the fact that the average speed of senior players was a little faster than that of open players. This was seen as reasonable because open players who are capable of reading a game and who know their movement capabilities need not move as quickly while senior players know that if they don't 'keep going' then they will not get there in time.

Data summary: referees

The following statistical player data was collated on referees:

Total number of recordings:	72
Spread of (known) player ages:	Youngest – 17, Oldest – 44
Average distance travelled in a game:	5,060m
Longest distance travelled in a game:	5,700m
Average speed throughout a game:	5.2 KPH
Fastest speed recorded:	Male – 25.4 KPH, Female – 28.2 KPH
Highest heart rate recorded:	Male – 212 BPM, Female – 215 BPM

Although the majority of games were under the control of three referees, they continue to run further than players in an average game (average 5,060 metres compared with 3,120 metres). Referees also tend to have a faster average speed than the average speed of players, probably because they don't have substitution boxes in which they can stand still or move very slowly. Even through there are three referees in any one game, only one of them usually performs the (formal) central, adjudication role while the other two act as line referees. They may get some respite here often only for a very short period, before they again take the central position as the roles rotate.

It is of some concern that during three or four day tournaments, many referees are moving distances of half-marathons on each of the preliminary tournament days. The issue is that towards the end of the tournament, around semi-final time, it is expected that these same referees are performing at their best and ensuring no game-deciding, decision errors are made. Thus it is expected that representative referees achieve and maintain a very high standard of fitness commensurate with game requirements.

More analysis of referee data needs to occur so that appropriate training programs can be developed and implemented.

Game analysis – movement, skills and fitness

The game of Touch can be broken down into a series of running movement patterns separated by intervals of standing still, walking, jogging or some half- paced movement used for positioning or recovering. There are a very few times when players and referees may approach their maximal sprinting speed and even appear to move close to maximal speed. This usually happens during an intercept, either from the attacking or defending perspective. Various fitness training and conditioning programs that are currently in place for both players and referees tend to address these movement patterns and other factors so that they are able to meet the physical demands of the sport and also to assist with avoidance of injury.

Both general and specific playing skills are often undertaken while moving in relation to the playing field. Skills such as catching, passing, dumping, sidestepping, swerving and making touches are all usually performed while some movement across the ground, in various combinations of forward / backward and lateral, within the field confines occurs. Even the dump skill, which has evolved from the stationery rollball, is performed while a player is moving, sometimes close to three-quarters of maximal speed. Movement to position or re-position without possession of the ball, is a prime example of game movement activity, especially for defending players and what is often overlooked, also for attacking players.

Specific game movement activities from a player's perspective, i.e. running, walking or standing, are usually performed with some level of forward, lateral or rearward movement and include:

- Running, walking or standing with the ball (any combination of forward or backward, with or without an element of lateral direction, usually attempting to evade defenders, while passing the ball or performing a dump)
- Running, walking or standing in attacking support (any combination of forward or backward, with or without an element of lateral direction, positioning to receive the ball, in preparation for additional support or simply to deceive defenders)
- Running, walking or standing in a defensive role (any combination of forward or backward, with or without an element of lateral direction and usually involving shadowing the opposition players, making touches or moving to cover other defenders)
- Diving or falling (usually in a forward or sideways direction, with or without lateral movement, usually either as a player attempting to score under pressure or as a defender attempting a touch)

The amount of running, walking or standing required in the game usually depends on the number of substitutes in the team, the style of play (including the nature of any specific game which is also dependent on the actions, number of players and plays of the opposition) and the playing position of the individual. Of course the amount of activity also depends on personal issues such as general fitness, psychological and motivational elements, game plans, specific coach instructions and the like.

This preliminary project did not take into consider player positional data. It would seem logical to assume that middle players, who generally appear to have more contact with the ball and who appear to have more demanding defensive commitments, would generally undertake more active running than the two link players. In turn, it would also seem likely that the links would undertake more frequent, active running than the two wingers, although it would seem that wingers generally may make longer runs than other players. It is apparent that the majority of movement is completed without the ball and much movement is (or at least should be) done off-the-ball. Simple logic and statistical breakdown confirms this as follows:

- A game consists of two twenty-minute halves, with approximately five minutes of 'dead' time (i.e. thirty-five minutes of game play)
- If each team has 50% possession, each team has the ball for approximately seventeen-and-a-half minutes (this may vary)

- If each team has a compliment of fourteen players, each player (on average, acknowledging that middle players may have possession more times than other positions) thus spends:
  - Approximately one minute and 25 seconds with the ball (given that all players, middles, links and wingers equally share possession)
  - Approximately thirty-three minutes and 35 seconds without the ball (both as a defender and in supporting attack)

An area which has significant significance on the game is the rate that a player / referee actually moves from one movement activity (running, walking or standing) to another activity i.e. acceleration or deceleration. Acceleration or deceleration can be defined as the rate of change of velocity of the body and must not be confused with pure or raw speed (velocity) of the body. In the modern game it would seem that quality acceleration is more important than raw speed. More than half the game-time is spent in acceleration.

Deceleration on the other hand is the act of no longer accelerating or maintaining speed, when one is actually reducing speed, and is one of the most misunderstood and underestimated activities in the modern game. Deceleration is important for evasion, balance, positioning and to effectively perform numerous individual skills such as passing, making a touch and dumping.

Current training programs

Traditional training programs for Touch involve the initial establishment of an aerobic base followed by exhausting and (often) painful endurance programs leading then to specific match conditioning refinements for speed. Endurance drills are regularly performed at a lower intensity and tend to rely on greater contributions from the aerobic system. Many training programs consist of repetitions of lengthy, if not longer sprinting distances, in an effort to achieve game endurance.

Many coaches continue to use those large amounts of long and middle distance endurance training although the Allan project way back in 1983, based on the statistical data on maximum sprinting distances identified in the game, highlighted that less importance should be provided to middle distance (400 and 800 metre-type) training activities. The value of longer distance (5 km plus - aerobic) training to the modern-day game has also been questioned. The question may be simply put, “Do we need an aerobic base to training correctly for Touch?”

Further, this project involved a brief analysis of the average distance and speed of game sprints and how they compared with an individual’s maximal speed. Many training programs involve 40 and 50 metre sprint training, with the coaching objective of securing or improving speed, speed endurance and even lactate tolerance. If we are to correctly apply the sound training principle of specificity, perhaps fitness training programs should more accurately reflect the requirements of the game?

While there have been several attempts to define the physical requirements of the game, few remain valid and current. One needs only do a ‘Google search’ to find that a similar sport has a generic requirement of:

- Explosive acceleration and fast sprinting speed
- Muscular endurance and strength in both the lower and upper body
- Muscular balance and high levels of neuromuscular co-ordination
- Proprioception (the sense that indicates whether the body is moving with required effort, as well as where the various parts of the body are located in relation to each other) and agility, the ability to know where your body is and be able to move it
- Good flexibility to avoid injury, and to give yourself a greater range of movement
- Correct balance between your quadriceps and hamstrings, as well as strength imbalances between your left and right leg

So we need to clearly identify our requirements. The following briefly discusses some fitness aspects of the game.

Speed, acceleration and deceleration

The game is primarily dependent on movement and ball handling. Excluding the latter, the speed of movement is an important factor and 'faster' is generally better. Speed is an integral part of every sport and can be expressed as any one of, or a combination of the following elements: maximum speed, elastic strength (power) and speed endurance. Speed and movement acquire energy from three different sources.

Energy for absolute speed is supplied by the anaerobic alactic pathway. The anaerobic (without oxygen) alactic (without lactate) energy system is best challenged as an athlete approaches top speed at around 40 metres while running at 95% to 100% of maximum. This speed component of anaerobic metabolism lasts for approximately six seconds and should be trained when no muscle fatigue is present (usually after 24 to 36 hours of rest). Note the distance 40 metres.

While speed is important to the game, depending on the individual, it takes 30 to 60 metres to achieve top (absolute) individual speed. Because the data indicates that very few game movements (accelerative or decelerative) extend beyond 20 metres in any direction, (both in attack and in defence), it is therefore apparent that raw speed is rarely seen. In fact the only times that players approach top speed is during an intercept. The average percentage of time a player spends over half-pace, (specified as Speed Zone 4 – or over 17 KPH) is less than 4%, or in practical terms, about 100 seconds in a game. Our training therefore must represent this.

To develop effective speed, style and technique are important. Running techniques should be rehearsed at slow speeds and then transferred to runs at maximum speed. The stimulation, excitation and correct firing order of the motor units, composed of a motor nerve (Neuron) and the group of muscles that it supplies, makes it possible for high frequency movements to occur. The whole process is not clear but the complex coordination and timing of the motor units and muscles most certainly must be rehearsed at high speeds to implant the correct patterns.

Stride length is a factor of raw speed. Stride length can be improved by developing muscular strength, power, strength endurance and running technique. The development of speed is highly specific and to achieve it we should ensure that:

- Flexibility is developed and maintained all year round
- Strength and speed are developed in parallel
- Skill development (technique) is pre-learned, rehearsed and perfected before it is done at high speed levels
- Speed training is performed by using high velocity for brief intervals. This will ultimately bring into play the correct neuromuscular pathways and energy sources used

But stride length is even more important when applied to acceleration. Taking steps that are too long will significantly reduce acceleration. In the acceleration process, in addition to having most parts of the body balanced and ready, players need to get full extension and run with a pushing action for as far as possible. This means staying very forward with the whole body and keeping the head down or forward will also assist. The players should aim to impact with their lower legs (tibia) pointing backward. And of course as attacking acceleration mainly occurs with the ball, consideration must be given to specificity of training (i.e. accelerating with the ball in the hands). The game is 50% attack and 50% defence and we should train accordingly.

Speed is chiefly determined by the capacity to apply a large amount of force in a short period of time. This is also known as power. Many athletic movements take place in 0.1 to 0.2 seconds but maximal force production takes 0.6 to 0.8 seconds. The athlete who can apply most force in the short period of available time is said to be the most powerful. This is particularly relevant to our game.

Even for development of raw (absolute) speed most training techniques involve shorter rather than longer distances. This supports the contention that training programs should review sprinting distances with a view to reducing them. The distances usually involve an upper limit of 3-4 seconds at maximum speed, i.e. about 30 to 40 metres from a standing start. Rather than doing 10 x 400 metre sprints, we should be looking at 400 x 10 metre sprints!

Strength training increases maximal force production. Assuming as a result, more force can be produced in the same period of time, strength training alone can increase power. However it makes more sense to increase both maximal force production and the rate of force development. This can be achieved through training for power. Both strength and power training are integral to improvement of speed

Strength training is a major component in development of speed and general player performance. Therefore building a working foundation through strength training should be a major focus. Speed training drills and exercises need to focus on improving acceleration and pure speed. Remember it is not pure speed that is important in our physical game – it is the ability to accelerate and decelerate that is important. An associated element of course is the attacking skill of evasion. Evasion cannot be executed at full speed and an element of deceleration must occur.

The combined skill of effective evasion and deceleration is determined by the amount of deceleration, coming to a complete stop or a slight hesitation and is due to several factors. The first being the speed at which the player is moving coming into the change of direction. Obviously the faster the player is moving the more control is needed to decelerate the body. Secondly, the angle at which the change of direction is going to be made. If a player is going to change direction at an angle of 10-15 degrees the deceleration doesn't need to be as great to control the body and to make the swerve or change efficient as if the angle was 90 degrees.

The third factor that determines how much deceleration is needed is the issue of balance, with the ball. A player with poor balance will need to decelerate much more than a player that can change direction easily without any loss of control and with minimum speed degradation. Evasion requires great body control, especially balance of the body. This factor should influence our training because simple deceleration training has a little more to it than just stopping and starting.

There are several different “types” of deceleration and to conduct deceleration effectively there are some fundamental concepts and laws of movement that need to be applied. Biomechanics are involved. It should also be remembered that not all deceleration ends with a player in a stationery position and much of the time deceleration involves a swerving movement or simply changing directions while maintaining some degree of speed.

From a biomechanical aspect, when a player comes to a direct stop the shoulders will lower vertically over the hips to maintain balance whereas if evasion or changing direction is undertaken, the shoulders stay to the inside of the hips on an angle that is in line with the supported leg, assisting and driving the player in the desired direction. This action allows players to move or swerve more quickly without having lag time or swaying. Additionally, if the player comes to a complete stop the hips must lower to create a better balanced situation and to control momentum. But when a player twists or evades an opponent simply by swerving, the hips don't actively lower in height. The hips may lower slightly due to the angle of the swerving leg being outside of the vertical axis of the body. This will automatically lower the hips but by not lowering the hips too much the action can be quick, elusive and allow the player to maintain most of the required evasive speed.

Many explosive movements can involve the reflex/elastic properties of the muscle-tendon complex and are ballistic in nature, even when initiated from a static position. The action begins with a preparatory countermovement where the involved muscles are rapidly and forcibly lengthened or "stretch loaded", and immediately shortened in a reactive or elastic manner. This eccentric-concentric coupling phenomenon usually referred to as the ‘stretch-shortening cycle’ (SSC) is often observed in sports involving running, evasion and with rapid changes in speed and direction. SSC actions exploit motor-neural reflexes as well as intrinsic qualities of the muscle-tendon complex. Although the exact relationship of reflex/elastic properties of the muscle-tendon complex to maximum strength is not completely understood there does appear to be a degree of independence, thus training for maximum strength will not optimally train these properties.

Training for such sports should therefore progressively include plyometric methods in addition to basic "heavy resistance" movements. In this way the inherent elastic properties of the muscles will be developed. Heavy resistance is briefly discussed under strength training below. In recent years, this distinct method of training for power or explosiveness has been termed plyometrics. The term is used to describe the method of training that seeks to enhance the explosive reaction of the individual through powerful muscular contractions because of rapid eccentric contractions. Exercises include drop jumping, bounding and hurdling. Plyometrics would seem to be an ideal training method for our game.

Unfortunately the capacity for any player to reach a level of training is pre-ordained. The ultimate potential for explosive movements is determined by the fast-twitch composition of muscles and probably by the nature of the ATPase secreted by the respective fibers' cross-bridging.

ATPases are a class of enzyme that catalyze the decomposition of adenosine triphosphate (ATP) into adenosine diphosphate (ADP) and a free phosphate ion. This dephosphorylation reaction releases energy, which the enzyme (in most cases) harnesses to drive other chemical reactions that would not otherwise occur. This process is widely used in all known forms of life.

Strength training

There is tremendous potential to improve a player's performance capability and also minimize the risk of injury through specialized strength training. Principle-based planning and implementation of the preparation process is the key. This requires a working knowledge of physiological and biomechanical bases of maximum strength, speed-strength and strength-endurance development. The following practical implications are recommended for any strength training program:

- Explosive force application is the basis of strength training for sports. Functional strength is expressed in terms of acceleration, execution time or velocity – especially in our running game. Training tactics which disregard this fact are fundamentally unsound. Moving through an acceleration path and applying rapid and / or high-speed force, is the name of the game.
- Emphasize big basic movements which have the greatest training effects. Muscles act in functional task groups and must be targeted via force transmission through (rather than isolation within) the body's "kinetic chain". Multi-joint free weight movements are superior in this regard. Use free weights to improve passing accuracy and distance.
- Distinguish between specificity and simulation. Training tasks should be selected and prioritized according to the coordinative, biomechanical and bio-energetic demands of competition.
- Balance the need for specificity vs. variability. Maintain stability in the program by sticking with a basic exercise menu rather than trying to include every possible movement. Variation can be achieved by cycling workloads on a 'periodic' 3-4 week basis in order to summate their training effects and avoid accommodation problems.

- Quality not quantity, of effort is the bottom line. While it is necessary to do enough work to get a training effect, there is likely a threshold of diminishing returns above which a player's effort is diluted – and recoverability / adaptability are compromised. Fitness and fatigue are a trade-off beyond a certain point. Generally, the best results are achieved by maximizing the quality of effort within a prescribed amount of work.
- Effort and recovery are interdependent. The interrelation of workload, intensity, frequency and volume cannot be changed arbitrarily. They must be adjusted together, which occurs automatically with a sound plan. A training program is only as good as the player's ability to recover from and adapt to it.
- Fitness qualities are means toward an end, not the end alone. To develop performance capabilities and skills, and thereby couple effort with execution power, flexibility, agility, speed and endurance – combined with motor coordination – are the elements of athleticism. Each part can be trained, but they must be trained collectively because they are parts of a larger whole. None is a separate entity, nor more important than another. And remember to train athletes, not muscles!
- Most importantly, skillful tasks are the basis of sports training and require the services of qualified people. Skilled training requires skilled coaching and without skilled coaches any program will be ineffective.

Reaction time and sport specific training

One concern with this project relates to the time period between recorded data readings. Every second there was a reading between one of several satellites and the harnessed recording unit. Unfortunately in one second, many players made movements that were not recorded. A player who was 'recorded' as being stationary (in the same spot on the field) may have started to move in one direction, propped and then returned to the same (starting) position in the one-second period. While this was recorded as stationary, the player may have actually moved and exerted some energy.

Of note, some players may have moved in more than one direction, over a very short distance, and also had no movement recorded. While the movement itself may not be critical to training programs, the associated reaction time is worthy of comment.

Reaction time, reflexes, quickness, or whatever the response action is called, is a complex function that includes mental, physical, innate and learned components. Studies have shown that reaction time, the period between the introduction of a stimulus and the first observable response, can certainly be improved. There will always be individual differences (as there are with the percentage of fast twitch muscle fibers), but each player can learn to improve reaction time.

Reaction time is important more so for defenders than attacking players. The process loop is the important factor for reaction time. We have to be sure the player can take the stimulus, whether it be verbal, visual, tactile, or in some other form, and then turn it into a response. A person can have great reaction time, but it doesn't help if his or her body can't do anything about the stimulus. You have to be able to take advantage of the process. That means being in the right body position, with the feet, arms, head, body, etc at all the right angles, to take advantage of the situation. Therefore we need to train for these things.

But for the moment, put reaction time aside and consider sport-specific training. There is ample evidence that strength training, aerobic and anaerobic development, agility and reaction-time training, together with all those game skills should be practiced in a manner that simulate game or event conditions. Remember specificity.

Movements that are practiced in game-like situations are the ones most likely to be used in competition. However, non-specific drills that still occupy valuable training time should be questioned, and when justified not necessarily discontinued. Some of them may be defended on the basis of general conditioning, flexibility, variety, cross-training or developing general motor abilities. But many things that happen during games, matches, or events often show little or no connection for what goes on during training.

That is why coaches spend much of their time planning drills and activities that are most specific to the game. Nevertheless, there is a place in the training routine for less-than-sport-specific activities. We can learn much from other sports. If track athletes can become quicker through experience and anticipation, so can competitors in other sports. It's even more valuable if they practice reaction time in the context of game situations in their respective sports.

So there are three take-home ideas here about reaction time. The first is to develop ways to do something with your body to react to a stimulus. The second is to develop basic motor skills that are needed to play a sport, and the third is to incorporate both components into competitive situations.

Agility

Agility is often an under-rated element of the game. Agility is an important element of running with the ball, dumping at speed, evasion, deceleration, recovering after a touch and simple positioning. Of particular interest also is a defending player's ability to quickly react to an attacker's change of direction or evasion move. This is usually dependent on a defender's balance, anticipation and of course the resultant reaction, commonly called 'foot speed'.

Most team sports consist of very few movements that occur only in a straight line. Nor do those movements occur at a fixed pace or for a fixed length of time. Agility and quickness training improves an athlete's ability to change direction, brake suddenly and perform sport-specific skills with speed and dexterity.

Compare speed training to strength training for a moment. A sport specific strength training program should aim to develop basic strength. This is on the premise that a solid base of strength offers greater physical potential to work with when converting it to sport-specific strength later on. Basic speed training along with power training maximises the athlete's ability to move rapidly. Agility training helps an athlete to apply their speed to sport-specific scenarios.

Agility training programs should focus on the use of balance, strength and power in multi-directional planes. The agility ladder is a useful piece of sports training equipment designed to enhance body control and increase foot speed. An agility ladder forces players to quickly move their feet in and out of a square-shaped box. The player can move in forward, sideways and backwards directions and in various combinations to different cadences. The agility ladder teaches swerving in and out and change of direction skills.

Endurance and lactic acid

Endurance training, with respect to most sports, relates to the ability to continually produce maximum power on each play throughout the entire game. It is a common mistake for most players to train for endurance by running long slow distances. This is certainly the case for many of our players (and even coaches).

Endurance is about training the body to withstand repeated sets of six and a short review of the energy systems may be appropriate. Carbohydrates along with fat, provides energy to the cells of the body. It can be stored in muscles as glycogen or it can be obtained directly from the bloodstream as glucose. When either glycogen or glucose is broken down completely to provide energy, oxygen is needed for the process to be complete. The process is called aerobic metabolism. When there is not enough oxygen available in active skeletal muscle cells, the process cannot be completed and lactic acid begins to appear in the muscles being exercised. This Lactic Acid eventually moves out of the muscles, but several misconceptions exist about how it forms and when it is removed.

The formation of lactic acid during intense exercise or sports competition is the probable cause of the uncomfortable burning sensation that occurs in muscles as fatigue sets in. The appearance of lactic acid during exercise can be taken as an indication of poor aerobic (lactate threshold, cardiovascular) fitness. When performing at the same exercise intensity, less lactic acid production means a better state of aerobic fitness and the ability to better withstand the onset of lactate threshold.

Lactic acid rapidly moves out of the muscle cells by the circulatory system and from blood and fluid by the body's metabolic process into the blood stream and levels in muscles generally return to normal (resting) values within 15-30 minutes. Low intensity aerobic exercise can actually speed up the process. In high-intensity exercise lasting 10-30 seconds, depletion of high-energy phosphates and neuromuscular fatigue results in diminished performance.

What training should be directed towards is a true ‘energy system development’, meaning that players can withstand higher levels of lactic acid before experiencing exhaustion.

Conclusions

This preliminary game movement project would appear to have rekindled an interest in our physical training programs. Any program must be specific to the needs of the game and as such, the game requirements must be available and presented in accurate and understandable terms.

In order to maximize the players' performance capabilities, the training preparation process must be planned and implemented according to sound principles. In terms of movement patterns, the distances covered, including speed related distances and especially the percentage of time in various speed zones have been quite enlightening. There is little doubt that more research needs to be done.

In terms of specificity, training tasks should continue to be selected and prioritized according to their dynamic correspondence with the demands of the game (specificity or transfer of training effect). This especially means a re-think in the running distances used in fitness training programs. This also means a re-consideration of the philosophy of keeping players intimately involved while in the sub box. Perhaps there is a requirement to initiate a new game skill – that of being able to quickly and effectively turn on and turn off – perhaps this is an innate skill of some champions?

Speed and the ability to accelerate and decelerate must be viewed in game context. The rate of force development and time of force production and dynamics of effort are especially important criteria in explosive movements. Other practical considerations include amplitude and direction of movement, accentuated region of force application, and regime of muscular work. While these may appear to be statements of common sense, it is difficult to overstate their importance because failure to address them in training can result in limited transfer to competitive performance.

Recommendations

As a result of this project the following recommendations are made:

- A more thorough analysis of the available data should be undertaken, especially regarding gender differences.
- Specific analysis of referee data should be undertaken.
- Data needs to be separated into player-positional variants. Whether there is a different physical fitness requirement for wingers, links and middles needs to be identified.
- Further data should be collected and collated on a gender and age basis.
- Consideration should be given to the collection of subsequent recording data together with video images of subjects.
- Further research into heart rates in the sub box should occur.
- As updates to more-frequent-data-recordings-per-second become available, the equipment should be upgraded.

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Internet web sites

While other web site references were made during the development of this report, the following web sites will provide further information regarding movement patterns, speed, agility, strength and the like and especially details related to training program design and planning.

www.gpsports.com
www.sportsspeedetc.com
www.sportspecific.com
www.thesportjournal.org
www.Sports-Coach.net
www.brianmac.demon.co.uk
www.40speed.com
www.expertspeedtraining.com
www.ultimatespeedinc.com
www.athletesacceleration.com
www.sport-fitness-advisor.com
www.jumpusa.com
www.nestacertified.com
www.Gumtree.com
www.agilitydogs.net
www.endurancetraining.com.au
www.boulderperformance.net
www.netfit.co.uk/rugby-cornwallwen.htm
www.healthfitness.com.au
www.tri-ecoach.com
www.peakperformpt.com
www.athletesedge.com
www.oztrack.com