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Editorial

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Dear readers:

At the end of the fourth year of publication of IJCSS it is high time to thank all the reviewers for their valuable work. Their professional comments and suggestions have often assisted authors to further improve their papers.

Two main areas of research of *Computer Science in Sport* are *Modelling and Simulation* – in particular as applied to game and performance analysis – and *Multimedia and Presentation*. All of the contributions included within this issue fall into these fields:

Natalia Balagué and **Carlota Torrents** promote the practice of thinking before computing and introduces some alternative concepts, methods and tools based on a complex understanding of performance to develop alternative modelling approaches.

The purpose of the study performed by **Peter O'Donoghue** is to compare different tournament designs using simulation methods. He uses the All-Ireland Gaelic Football Championship as an example for his investigations.

In the paper by **Jürgen Perl**, a *Performance Potential Metamodel* (*PerPot*) is applied to predict performance. *PerPot* models the interaction between training input and performance output in adaptive physiologic processes by means of antagonistic dynamics. Training input causes two concurrent effects – a performance improving response flow and a performance reducing strain flow. The model makes transparent how the interaction between load and performance works and what the role and meaning of delays are. Perl demonstrates that prediction works well and can be used for developing schedules.

Arnold Baca, **Christian Eder** and **Oliver Strubreither** report on the application of a sports oriented concept for developing multimedia learning and teaching materials. In contrast to many other multimedia systems used as eLearning tools in sport science, the starting points of their systems are sports and not disciplines. Questions related to these sports are asked and then answered from the perspective of sport scientific disciplines in a highly interdisciplinary way.

In his second paper within this issue **Peter O'Donoghue** together with **Ray Ponting** derives an equation for the number of matches required for stable performance profiles. The equation was tested and validated in a computerised simulation.

The short communication of **Mauricio Radovan** and **Anthony N Kirkbride** describes a novel approach to the visualization of complex cricket data. The objective is to present results to the target audience in a friendly and easily understandable manner.

If you have any questions, comments, suggestions and points of criticism, please send them to me.

Good reading!

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THINKING BEFORE COMPUTING: CHANGING APPROACHES IN SPORTS PERFORMANCE

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Abstract

Thinking after computing is nowadays a common practice encouraged by the availability of faster and more powerful computers. The question is if the computed results are really helping and solving the main questions posed by coaches, athletes and sport scientists. To make computers more useful it is time to focus on theory.

Despite the complex nature of sport performance is recognised, traditional movement and training sciences rarely apply concepts, tools and methods designed to analyse the dynamics of complex systems. Current available research, based almost exclusively on a classical scientific paradigm, often offers a poor and sometimes confusing understanding of phenomena related to performance. One main consequence of this is an increasing distance between theory and practice that characterizes training science.

Besides promoting the practice of thinking before computing the aim of this paper is to introduce some alternative concepts, methods and tools based on a complex understanding of performance. Some practical applications of recent research using these tools will be presented in order to encourage computer scientists to develop alternative modelling approaches.

KEY WORDS: COMPLEX SYSTEMS, COMPUTER SCIENCE, DYNAMICAL SYSTEMS THEORY, PERFORMANCE, SOFT COMPUTING

Introduction

The improvements in the field of computer science over the recent years have reduced a lot the problems of computing. This situation paradoxically sometimes leads to a misuse of computers: thinking after computing is a general practice that may limit the advancement of science, especially when the research assumptions and the nature of the research -confirmatory or exploratory- are not taken into consideration.

It is important to bear in mind that we decide what we want to study and how we do it (Perl, Lames & Glitsch, 2002). Neither measurements nor science are neutral and it is worth pointing out that when we measure we miss more information than we gain, regardless of rigorous and well conceived measurement protocols. Our decisions regarding strategies for collecting data, processing information and presenting the results are part of the research process and are connected with our way of thinking. A good example of this process is represented by the research applied to sport performance.

Sport performance has been traditionally deeply influenced by the analytic reductionism. Despite the recognised limitations of the traditional models, the dominant conceptual structure is still based on a Cartesian view that conceives the body as a machine divided into parts and the performance as the sum of different qualities. This understanding of athletes and sport performance (that will be considered from now on as the simple approach) is in agreement with the available common tools to study it (based on the experimental model).

On the other side, there is a common agreement on considering the complex nature of sport performance related phenomena and a constant reference to the need to integrate all aspects and promote holistic proposals in the training of athletes and teams. The recent development of concepts and tools from the dynamic systems approach and computer science nowadays offer a chance to cope with this complexity. Unfortunately there is still a limited knowledge and use of the new concepts and tools and the available research is still processing the information in the traditional way, confirming that the more difficult task is changing the way of thinking.

In this paper both paradigms (simple and complex) will be tackled concerning some of the main traits for the development of a new theory, practice and research of sport performance. The focus will be placed on contrasting both paradigms respect some of the available evaluation tools. Practical applications using alternative tools to the study of sport performance will be introduced with the aim to help computer scientists to find alternative modelling approaches. Far from trying to present a complete epistemological context or present all the available mentioned alternative tools, the paper aims to show the importance of changing the way of thinking for contributing to a further development of sports science.

From simple to complex understanding of performance

The analytic reductionism has deeply contributed to the current understanding of performance. Research based on this classical approach has achieved important success and, due in part to it, training science and performance analysis have been developed enormously over the past few decades (Hughes, 2004). Nevertheless, although simple models work quite well in the study of closed linear systems they show natural limitations in the study of biological systems that are open and non-linear.

Different theories developed during the 20th century have led to an important change in various branches of the science. The holistic conception of living organisms interacting with the environment and the discovery of equations able to describe the non linear behaviour of human beings has revolutionize knowledge of different areas such as mathematics, physics, psychology or economy. The new theories do not only attempt to reduce the systems to components (simple systems) but try to study them more holistically, focusing on their basic organizational principles (complex systems). These principles are usually common for systems and mainly determine the behaviour of dynamic complex systems like living systems. The self-organising phenomena will characterise them, giving rise to similar behaviour patterns.

In accordance with a simple understanding of performance, group statistical analysis and experimental model-based designs are the dominant tools used in sport research. There is no doubt about the robustness of the experimental designs, but most of the current questions addressed by coaches to sport researchers do not refer to an "average person" or to getting "average results". Alternative tools and analysis techniques are needed to get more detailed information about individual responses and dynamic interactions between variables (i.e. single-subject analysis). On the other hand, new variables previously ignored or considered as noise or error (i.e. variability of biological responses, fluctuations) emerge as the result of non-linear interactions and the need to explain global behaviour and get qualitative information. Suitable tools of analysis to examine the non-linear dynamics of these phenomena are needed to provide new insights into sports performance.

Mathematics and computer science have a major role because they help to build the models that reduce the complexity of the system without dividing it into parts. The implicit acceptance of the influence of all parts of the organism and the environment on the subject's ultimate behaviour and the existence of general principles applying to all systems is promoting interdisciplinary work and providing a challenge for computer scientists.

Researchers (together with coaches and also athletes) can contribute notably to the development of sports performance and coaching science by overcoming their fear of change and trying different approaches (or let others do so).

Table 1 shows a summary of some traits that characterise the simple approach to sports performance, contrasting with the alternative dynamic complex systems approach. According to the simple approach human beings are considered as closed linear systems where cause-effect relations between inputs and outputs occur. Simple systems have been during centuries the only studied despite they are an exception in nature. According to the complex approach living systems are structurally open because they are related to a constant flow of material and energy and organically closed because they self-organise. The contrast between the characteristic traits of both approaches will be further developed in the next sections of the paper.

Table 1. Contrast of some characteristics and views of simple and complex understanding of performance

SIMPLE	COMPLEX
Linear close system	Non-linear open system
Hierarchical Cognitive process	Heterarchical Self-organisation process
Errors	Variability/Fluctuations
Cause-effect relations	Interactions
Analytic view	Global view
Quantitative	Qualitative
Evaluation of states	Evaluation of processes
Generality	Individuality
Robustness	Sensitivity
Reductionism	Holism
Determinism	Uncertainty
Homogeneity	Differences

From a hierarchical cognitive process to a heterarchical self-organisation process

One of the main differences between the simple and the complex approach is the different understanding of the adaptation and learning mechanisms of the systems involved in sports performance.
From the simple approach the adaptation mechanism is based on cybernetics and uses the so-called computer metaphor. According to the computer metaphor athletes are equipped with a central processor (the brain) with great cognitive capacities –in hierarchical relation with respect to the rest of body structures and functions. This processor should be previously programmed (usually by the coach). No correct response is expected without pre-programming. In this context it is expected that the selected inputs (training stimuli) produce, after the central processing of the information, the right outputs (the performance response). As outputs should be in agreement with the pre-programming and there is, in general, just one possible correct solution or response (the right techniques, the right tactics), any deviation in the response is considered as an error. If the athlete is not able to produce the right outputs in the initial phases, it is believed that he or she will progress through the repetition of the input-output sequence and comparison of the outputs with the reference response (Temprado & Laurent, 1999). The regulator systems the athlete is provided with allow current performance to be constantly compared with the rehearsed objective in order to avoid errors. In case the system by itself is not able to give the right feedback, the coach will help through verbal instructions, corrections, etc. Other feedback systems and notational analysis will also help in this direction (Hughes & Franks, 2004).
Following the dynamic complex systems approach the outputs or performance responses are individual, are never repeated and do not respond to a pre-established and pre-programmed pattern. It is not necessary for the athlete to know the solution beforehand; it emerges spontaneously from the synergetic organisation and interaction of the different constraints of the system in a self-organisation process (Kelso, 1995). From this point of view, the role of the coach and other feedback systems are restricted to one more constraint interacting in a heterarchical way. The concept of error is also changed. The variability of the responses is the necessary consequence of the interaction between many complex systems and constraints to produce a movement.
The interest to fixing or pre-establish the right outputs (conditional profiles, techniques, tactics…) is called into question as are the traditional input repetitions (Schöllhorn, 2000).

From errors to variability and fluctuations

The concept of the correct outputs or prototypes in the simple approach gives rise to the concept of error. Corrections of deviations from the pre-established programs are one of the main objectives of the training process. Repetitions and feedback systems (including the coach) are used when the performer is not able to reproduce a desired pattern. Feedback is a concept originated in engineering and cybernetic control theory for close-loop systems and is designed to keep stability adjusting the actual response with the reference output. The development of the feedback-based technologies has been very important in the last years (Liebermann & Franks, 2004) and its use has been spread despite its high costs in some cases. Verbal instructions, demonstrations and feedback systems trying to alert or detect errors have

not always been shown to be effective and sometimes might have negative consequences on performance (Hodges & Franks, 2004).
From the dynamical complex systems approach, variability, far from indicating the inability of the subject to perform, is expressing the interaction of many complex systems and constraints during the motor performance. Variability expresses flexibility of the system to adjust, select or change to new patterns and therefore adapt to changes. According to the dynamical systems theory (DST), variability and fluctuations are the necessary disturbances of the system in adapting and shifting into new forms. The study of variability of some biological functions (heart rate, respiration) shows interesting possibilities for evaluating the adaptive capacities in physiological systems (Goldberger, 1997). Ignored or interpreted as noise or error until recently, the analysis of the variability is a matter of interest demanding further research (James, 2004).
In addition, fluctuations and intermittencies of signals that are in general ignored, filtered, smoothed or considered as errors can be also considered as biological markers (Selles et al, 2001).
As has already been demonstrated in rhythmic movements (Kelso, 1995) the increase of fluctuations also precedes the change of state in other ballistic movements such as jumping (Torrents, 2005). Fluctuation analysis seems also to be helpful in determining other qualitative changes in performance, as occurs during muscular failure (Balagué & Torrents, 2003).

From linear cause-effect relations to nonlinear interactions in performance and competition

In relation with the mechanic conception of athletes and the computer metaphor a linear cause-effect relationship between load and performance is established in training and competition. If this linear relationship was the only observed, different athletes with the same training would obtain similar results, or by increasing the load, we would always obtain increased performance. Nevertheless athletes and coaches know that this is not so simple. In practice, training loads that drive some athletes to success do not cause changes or even cause overtraining in other athletes, and while a small training stimulus causes surprising improvements in some athletes, it does not cause any changes in others. Van Rossum (2000) points out the low level of correlation between the number of hours of practice and performance.
There is still a need to find appropriate theoretical approaches for this non-linear relationship between load and performance and also to have the adequate methods and tools for studying it available to us. However, a very interesting non-linear dynamic metamodel to understand non-linear interactions between load and performance has recently been developed (Perl, 2004). The PerPot (Performance Potential) metamodel is based on the antagonist concept. Each load impulse simultaneously feeds two potentials: the strain potential and the response potential. Both influence performance potential in an antagonistic way (increasing and reducing it, respectively) but with different delays. Effects of the load on the performance change depend on the delays. The relation between the delays specifies the performance profile. As potential capacities are limited potential overflows can occur and a reserve profile is defined. The metamodel gives a plausible explanation of the common observed phenomena related to performance (overtraining responses, atrophy processes…) and help to identify some striking features during training.
Also following a linear cause-effect relationship, the traditional competition analysis systems connect the number of successful actions of the players during the game with the results of

the competition. However we often see in game analysis how a superior team does not win the match. In fact there is a nonlinear relationship in game sports between level of skill, performance and success in competition, as well as between control of game, opportunity to score and scoring a goal (Lames, 1999).
The study of relative phases introduced by the DST provides information of the interaction or coordination between two systems with the advantage of compressing information about several variables into one measure (i.e., proximal and distal segments´ displacement and velocities) (Kurz & Stergiou, 2004). Even if the main applications of the study of relative phases are addressed to the gait analysis and the coordination of human movement, other possibilities have been recently checked. Instead of the classical analytical study of displacements in game sports, where each player is evaluated separately, the study of relative phases offers a chance to evaluate the interaction of the displacements between two opponents during the game. Some promising results have been obtained in tennis (Palut & Zanone, 2003; Lames, 2004). Another approach focusing on the interaction between opponents is the study of disturbances (Hughes et al., 1998).
As it will be reviewed later, Schöllhorn (2003) extends the time discrete measure of a relative phase to a continuous measurement of similarity transferring the approach to new applications.

From analytic to global view of performance and competition

The division of performance into components (physical, technical, tactical, psychological…) and sub-components (strength, speed, endurance…) that are trained separately is a common practice in sport training. The so-called multidisciplinary approach considers performance as being the result of the sum of each component. In fact a considerable effort is made in sport performance to mark clear boundaries (inexistent in reality) between each component and sub-component for training and testing purposes. Take, for instance, the evaluation of a basketball player. The concept of performance is atomised for testing purposes. We may be interested in testing the physical condition, the technique, the tactics…If we consider the physical condition we can plan to test the strength, endurance, velocity…Strength in turn is divided in explosive, maximum, resistance…Explosive strength can be divided into elastic, contractile…Finally, the available tests (for instance a squat jump), which are a product of such a performance breakdown, have very little to do with the jumps performed during a basketball match. Is this information helpful for the coach?
In a similar way, during strength training, each muscle is trained separately following the same analytical process. Some specific machines are designed to allow each muscle to work independently. Are those artificial machine exercises helpful for developing functional strength in the athlete or for preventing injuries during the competition?
Technical training exercises also usually break the body down into parts that are trained separately. A similar decomposition process of another complex system (the team) is produced in collective sports where players are trained and tested separately.
The influence of the reductionism and analytic view is also affecting the research process when collecting and analysing the data. Very often only discrete variables (resting, peak or threshold values) or mean values are considered in data collection that uses to be one-dimensional, analytic and focused on discrete time oriented approaches. In fact, compared to the attention paid to the development of accurate measurement instruments, very little attention is paid to data collection and analysis. As an alternative to classical reductionism using only time-discrete data for quantitative analysis, a holistic process-oriented approach, using time series analysis, is proposed, allowing us to get qualitative information about

patterns in time and compare them quantitatively (Schöllhorn & Bauer, 1998, Schöllhorn et al. 2002).
Reductionism is also present in data collection in game analysis. Isolated actions (shots, rebounds, lost passes…) of isolated players are recorded and analyzed (statistical analysis) in the belief that the sum of the number of successful actions is a measurement of performance in competition. However, teams can be also seen as complex systems that self-organise and their behaviour is the product of the interactions between the multiple constraints (also considering the opponents).
Lames (2003) includes four approaches to game analysis: stochastic modelling, neural network analysis, study of disturbances and relative phases.
Schöllhorn (2003), transfers the holistic process-oriented approach for detecting patterns in time to the space dimension. Instead of analyzing the spatial positions of single players separately, he also proposes the detection of patterns in space to get information about the relative positions of all players as well as information about "holistic" team qualities. Tools such as artificial neural networks permit recognition and classification of these patterns (Perl & Weber, 2004).

From evaluation of stable states to evaluation of dynamic processes in performance and competition

Periodical evaluation of an athlete's states at different points of the season is a very common practice in sport for diagnosis and prognosis purposes. Despite the carefully planned and administrated tests, important limitations are found related to the low predictive value of current testing methods. Researchers try to solve this by improving the validity, reliability and objectivity of the tests and focusing effort on developing increasing sophisticated technological instruments. Current biomechanical, physiological testing etc. involves great investment of money (instruments, qualified personal) and time compared, in general, to their contribution to the improvement of the training and competition process.
Tests use to be closed tasks with rigid protocols and are therefore a long way from reflecting the constantly changing situations produced during sports competition. If we also consider the constant development and change of the athlete during the training process, the use of classical tests is called into question. Coaches need information about the intrinsic dynamics of the athlete and how it changes more than they require an accurate quantification of a particular state.
The idea that shape states are stable and the cause-effect linear relationships established between testing results and performance are some of the main problems of the simple understanding of classical testing and evaluation.
From the point of view of the dynamical complex systems approach, some alternative explanations are found to the usual problems of testing and its lack of predictive value. The focus is not put on evaluating stable states but on the evaluating dynamic processes and non-linear interaction between variables.
In particular, alternative modelling and biologically motivated paradigms (fuzzy logic, ANN and genetic algorithms) allow us to:

- integrate interdisciplinary research adopting a system view,
- obtain qualitative information about dynamic processes,
- compress and deal with imprecise information,
- study interactions between non-linear variables and non-linear processes,
- develop systems able to learn and generalise from the learned matter (supervised artificial neural networks -ANN),

- learn and recognise unknown structures and classify pattern responses (unsupervised ANN),
- describe, analyse and evaluate continuous adaptation processes (dynamically controlled networks).

The application of modelling techniques and mainly so-called soft computing are suitable tools for evaluating performance as a non-linear dynamic complex process.

Conclusion

The use of computers in the study of performance- and training-related processes has been enormously expanded during the last years. The availability of faster and more powerful computers does not always seem to be an advantage if they are used in the wrong way. The need of thinking before computing is emphasized after the introduction of the dynamic complex systems approach in sport performance. Although all the processes and sub-processes concerned with performance are showing interactions and non-linear feedback, classical tools derived from classical mechanics and cybernetics are still used to study them. One of the main reasons for the classical simple understanding of performance is connected with the lack of availability of adequate tools to study it properly. Computer science has then an important role in the development of different approaches and our way to understand performance.

The application of modelling techniques and mainly so-called soft computing seem to be suitable tools for evaluating performance as a non-linear dynamic complex process. Modern computer scientists are challenged to develop such tools and, in turn, improve the computer-based concepts through sport research applications.

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THE ROLE OF SIMULATION IN SPORTS TOURNAMENT DESIGN FOR GAME SPORTS

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Abstract

There are many alternative structures to tournaments for game sports and over time tournaments have revised their structures. In making a revision to a tournament structure, there will be desirable characteristics that must be maintained or improved. Such characteristics include accurately ranking the strongest teams, increased revenue from audiences and sponsors and maintaining or improving player welfare. The purpose of the current investigation was to use the All-Ireland Gaelic Football Championship as an example of how alternative tournament designs can be compared using simulation packages written in MATLAB7.0.1. Desirable aspects of the pre-2001 and current structure of the tournament were compared when relevant progression statistics were accumulated during simulations. The simulation study revealed no significant difference in the strengths of the winning teams of the two tournament structures but did reveal that significantly stronger teams were losing finalists and semi-finalists in the current structure than in the pre-2001 structure. The proportions of winning teams, runners up and losing semi-finalists from different provinces was significantly different to the proportions of all teams that were from different provinces in both tournament structures investigated. This investigation has shown that computer simulation can efficiently provide information beneficial to decision making when designing sports tournaments.

KEY WORDS: SIMULATION, TOURNAMENT DESIGN, PERFORMANCE PREDICTION

Introduction

Performance evaluation is an essential activity in all branches of engineering including computing science. Performance evaluation topics include system tuning, bottleneck identification, workload characterisation, determining the resources required and predicting performance of a system at future workloads. Typical performance indicators for computer intensive systems include throughput, capacity, response time and resource utilisation. Performance evaluation techniques include measurement, simulation and analytical techniques. Measurement is used during system prototyping and system operation. Analytical techniques have the lowest cost, require the least time to apply but also have the lowest accuracy. Simulation studies are more accurate than analytical studies but less accurate than measurement studies. They require the use of simulation packages or programming which increases costs and time required. Techniques used in the development of computerised systems can also apply to the development of sports tournaments. Measurement is useful for characterising aspects of sports performance, but techniques that can be applied before the tournament structure is implemented are more desirable. The disadvantages of simulation relating to time and cost have reduced in recent years. Furthermore, the ability of simulation to report on detailed individual characteristics of systems makes its use to investigate the performance of proposed systems very attractive. The purpose of the current paper is to describe how simulation techniques can be applied to investigating systems in sport using the design of sports tournaments as an example.

The organisation of competition in sport depends on many factors including the nature of the sport itself. In sports such as running, swimming and cycling, races can be held that include all participants or races can be organised into heats and finals. The scope of the current paper is the design of tournaments for individual and team game sports. Sports tournaments can be organised as knock out tournaments or round-robin tournaments or a combination of both. In designing tournament structures, it is necessary to consider the total number of matches to be played, the number of matches to be played by individual teams as well as the chance of teams of different levels being successful. There are a very large number of permutations of how sports tournaments will progress making computer simulation a more attractive way of analysing alternative tournament designs than determining an analytical solution to a probabilistic model of a tournament. Simulation also allows flexible experimenting with tournament features and answering ad-hoc investigations of specific detailed features.

In order to be able to make assertions about properties of tournaments, such as the chances of the strongest teams winning, it is necessary to model tournaments in a way that allows such characteristics to be predicted. Mathematical models have been used to evaluate the probability of the superior player winning a tennis match against an inferior opponent when tie-breaks are used and when they are not (Carter Jr and Crews, 1974; Croucher, 1982; Fischer, 1980; Pollard, 1983). The information that can be derived from such models allows important decisions about tournaments to be made in a more informed manner. The current paper proposes to model entire tournaments rather than individual matches. Simulation has provided more accurate predictions of tournament outcomes than statistical, neural network and human expert based predictions for the 2002 FIFA World Cup (O'Donoghue *et al*., 2004), the 2003 Rugby World Cup (O'Donoghue and Williams, 2004) and the Euro 2004 soccer tournament (O'Donoghue, 2005). These prediction exercises attempted to correctly forecast the teams that would progress to the different rounds of the knockout stages as well as the teams that would eventually win the tournaments. Each of these simulators used models of soccer and rugby match outcomes based on relevant factors such as home advantage and team strength. They executed a large number (1000 to 2000) of simulated tournaments, accumulating progression statistics for the different teams involved. These progressions statistics were used to identify the most probable pool winners and runners up as well as the team most likely to win the overall tournament. The winner and runner-up of each pool were predicted as the team who won the pool most times and the remaining team that qualified from the pool most times respectively. The team that won the most simulated tournaments was selected as the predicted winner and placed in the appropriate positions in the rounds between the pool stages and final. The most likely team to reach the final in the other half of the knockout structure was predicted as the tournament runner up and placed in the appropriate positions in the other knockout rounds. The runner up team was not necessarily the second most likely team to win the tournament. For example, in O'Donoghue *et al*.'s (2004) simulation of the 2002 FIFA World Cup, the three teams most likely to win the tournament (Brazil, France and Argentina) could only reach the final through the same half of the knock out structure. This lead to Italy being predicted as the most likely tournament runners up. The other two semi-finalists were predicted as the two teams who progressed to the semi-finals in the other two quarters of the knockout structure most often during the set of simulated World Cups. When a tournament includes a 3rd place play-off, the predicted 3rd place team was the predicted losing semi-finalist that won the most 3rd place play-offs during the simulated tournaments. This team was not necessarily the team that won the most 3rd place play offs during the simulated tournaments. The remaining quarter-finalists were predicted as the teams most likely to reach the remaining 4 positions in the quarter-finals. This analysis of progression statistics was essential to produce a single prediction from a large number of simulated tournaments of varying outcomes. Such an analysis is not necessary in the current paper because the progression statistics provide the data necessary to characterise a tournament in terms of progression characteristics of teams of different strengths.

In designing tournaments, it would be beneficial to understand the important characteristics of tournaments and the effect alternative tournament designs have on these. The purpose of the current paper is to illustrate how simulation can provide information allowing alternative tournament designs to be compared. The All-Ireland Gaelic Football Championship is used as an example with the pre-2001 and current tournament designs being compared. The paper commences with brief reviews of tournament structures and issues to be considered in designing tournaments before describing the two versions of the example tournament to be compared. The methods and results of the simulation study are described and the use of simulation within sport is discussed.

Types of tournament structure for team games

When designing sports tournaments for game sports, there are many alternative mechanisms that can be implemented within the tournament design. The tournament could be organised as a round-robin tournament, a knockout tournament or a combination of both. A round-robin tournament of n teams where each pair of teams must play each other on m occasions will involve a total of $mn(n-1)/2$ matches with $m(n-1)$ matches for each team. There will be some round-robin tournaments where each pair of teams play each other once (for example a pool of the FIFA World Cup or the Rugby Union World Cup) and some where each pair of teams will play each other twice, once at each team's home venue (for example the domestic soccer leagues of England, Germany, Italy and Spain). The Scottish FA Premier League is a variation of a round robin tournament where each of the 12 teams plays the other 11 teams 3 times before the league is split in to 2 halves. The teams in the top 6 play each other for a 4th time and the teams in the bottom half play each other for a 4th time. This variation of the round-robin structure involves a total of $3n(n-1)/2 + 2[(n/2)(n/2 – 1)/2]$ matches with each time playing $3(n-1)+n/2-1$ matches.

Knockout tournaments work well with numbers of teams (or individuals) that are a whole power of 2. This allows half of the teams to be eliminated in each round until just 2 remain in the final. A knockout tournament of n teams (where n is a whole power of 2) will require $\log_2 n$ rounds of matches and a total of n-1 matches in the tournament if ties are settled with a single match. Where n is not a power of 2, $\log_2 n$ is rounded up to give the minimum number of rounds required. The number of matches required in the first round to reduce the number of teams to a whole power of 2 for the second round is $n – \log_2 n$ and there will still be a total of *n*-1 matches in the tournament. However, there are cases such as the English FA Cup where multiple preliminary rounds occur before the strongest sides enter. The total number of matches may also differ if there is a third place play-off match or indeed if ties involve more than one match, as has been the case in the knockout stages of the European Champions League, or when replays are allowed. There are some tournaments where ties involve a single match in some rounds but are played over 2 legs in other rounds. The League Cup for soccer in England is an example of such a tournament.

There are alternatives to the traditional knockout structures; one such alternative allows teams or players defeated in the early rounds to have a second chance; this is the double knockout mechanism described by McGarry and Schutz (1997). The structure described by McGarry and Schutz (1997) seeks not only to determine a winner but also to rank all of the teams. Without the need to rank all of the teams, eliminating all but the winning team in a traditional knockout tournament requires *n*-1 ties. Therefore, 2*n*-1 or 2*n*-2 ties will be required in the double knockout structure to eliminate all but the winning team, depending on whether the winning team loses a single match during the tournament or not respectively. Examples of double knockout tournament designs exist in Olympic beach volleyball and Gaelic football where teams or players are not knocked out in the early rounds unless they are defeated twice. In the knockout stages of tournaments, the type of tie that is played needs to be specified.

There are other tournaments that are combinations of round-robin and knockout structures. These include the European Champions League, where there are two stages of round-robin matches followed by a knockout stage, as well as most international soccer tournaments. The numbers of matches involved for each team as well as in total can be determined using detail already provided for round-robin and knockout structures. In some international netball tournaments, round-robin matches are used to classify teams into groups of four before crossover and play-off matches are used to determine the final rankings of teams within the tournament. For example, if four teams A, B, C and D are contesting the first four places there will be crossover matches between A and B as well as C and D. The two winners compete in the play-off for first place and the two losers compete in the play-off for third place. The use of crossover and play off matches for ranking purposes will add *n* matches to the tournament where there are *n* teams in the tournament. The disadvantage is that if the strongest 2 teams of the 4 play in a crossover match, only one of them will end the tournament ranked in the top 2.

Issues in Tournament Design

Home advantage is a major issue in sport that has been accepted to the extent that research efforts are no longer directed at identifying whether it exists or not but explaining why it exists (Courneya and Carron, 1992). Explanations for home advantage include distance travelled by away teams (Brown Jr *et al.*, 2002), familiarity with location and facilities (Loughead *et al.*, 2003) and evidence that crowd noise can influence refereeing decisions in favour of the home team (Nevill *et al.*, 2002). Therefore, tournaments need to decide whether matches will be played at neutral venues or if one team will be at home. International soccer tournaments are usually played in a single host country, although the African Cup of Nations 2000, Euro 2000 and the 2002 FIFA World Cup were co-hosted by two countries as will be the Euro 2008 tournament.

Entry to tournaments by elimination from higher level tournaments is also possible. For example, since the 1999-2000 season, some teams eliminated from the European Champions League enter the latter stages of the UEFA Cup. In some sports, types of matches need to be decided on. For example in tennis matches may be the best of 3 or 5 sets and may or may not involve tie-breaks.

Tournaments can be seeded to avoid higher ranked players or teams meeting too early in the tournaments (Chung and Hwang, 1978) and the possibility of seeding the participants that remain in the tournament at each round has also been suggested (Hwang, 1982). Seeding is an important issue in tournament design that can effect the chances of the tournament being won by one of the strongest teams. Where a knockout tournament of n teams is not seeded, there is a $(n/2\text{-}1)/(n\text{-}1)$ probability that the strongest two teams will meet before the final. Grand Slam tennis tournaments have 128 players in the first round of a senior singles event, 32 of whom are seeded. There will be 7 rounds of matches within the knockout event with seeds not meeting until the 3rd round. In addition to the highest 2 seeds not being able to meet until the final, none of the highest 4 seeds can meet until the semi-finals, none of the highest 8 seeds can meet until the quarter-finals and so on. The positioning of seeded players within the draw beyond these constraints can be done in a number of different ways. McGarry (1998) describes a scheme where the quarter-finals would be played between seeds 1 and 8, 4 and 5, 2 and 7 and finally 3 and 6 provided that the top 8 seeds reached the quarter-finals. In general in a round of k players where k is less than the number of seeds in the tournament, seed i will be due to play seed (k-i) in the scheme described by McGarry (1998). This will result in the top seed scheduled to have the easiest path to the final, with the 2 middle seeds expected to reach each round from the 3rd round onwards scheduled to play each other. An alternative scheme that would schedule seeds 1 and 5, 3 and 7, 2 and 6 and finally 4 and 8 to meet in the quarter-finals would involve seed i being due to play seed (i+k/2) in a round of k players. In reality neither of these schemes were used in Grand Slam tennis tournaments during 2005 as the placing of seeds between 3 and 4, then 5 and 8, then 9 and 16 and finally seeds between 17 and 32 can be drawn to allow a random allocation within the tournament structure while still ensuring that seeded players cannot meet until an appropriate round beyond the 3rd round of the tournament.

McGarry (1998) defines a sports tournament as "a formal system that seeks to rank entrants fairly in accord with their ability". Some tournaments, such as the World Netball Championships, do seek to determine world rankings after the tournament based on rankings achieved during the tournament. However, there are other tournaments where a winner is decided without producing a full ranking of participants. Knockout soccer tournaments would be typical of tournaments where teams do not play for ranking positions after they are eliminated. While determining a worthy winner or ranking participants according to their ability may be the most important outcomes of a tournament, there are other issues that need to be considered.

Different tournament structures will have an effect on important characteristics of the tournament relating the practicalities of organisation, entertainment value and the opportunity to win that teams and players of different strengths will have. Establishing a general set of precise performance indicators for all tournaments in all sports is not possible as different factors may have greater importance in some sports than others. However, the general characteristics of tournaments that can be operationally defined for individual tournaments can be discussed. The number of participants in a tournament, entertainment value, public interest, media exposure and advertising revenue are important issues that will influence decisions on the times at which matches are scheduled. It is difficult to say whether an increase in upsets will increase public interest in tournaments or not. Upsets make tournaments less predictable and more exciting as the outcome is not obvious. However, there may be high profile teams or individuals who the public are interested in (as supporters or neutral spectators) and the early elimination of such teams or individuals from tournaments might cause a decrease in interest. The difficulty of player and spectator travel during tournaments is affected by match schedules.

The number of participants in a tournament is an important issue that effects the duration of the tournament as well as the competitiveness of the matches. Where there are too few teams, high profile teams will be missing. However, if too many teams are allowed to compete in a tournament there may be mismatches with lower ranked teams suffering abnormally high losing margins to higher ranked teams. As the strength in depth of a sport grows, it is possible that the number of participants in a tournament can increase. For example, the FIFA World Cup has grown from having 16 teams in 1978 to 24 teams from 1982 to 1994 to having 32 teams in 1998 and 2002. The total number of matches to be played by each team or player is an important indicator of a tournament structure. Player welfare must be considered as short recovery times between matches can increase injury risk; there is evidence that increased training load is related to musculo-skeletal injury risk in military personnel (Almeida *et al*., 1999) and civilian runners (Bovens *et al*., 1989). Recovery days and travelling between countries when tournaments are co-hosted by two different countries can be considered together when designing tournaments. For example in the 2002 FIFA World Cup, there were 10 matches where one team had played their previous match in a different country while their opponents remained in the same country. In 9 of these matches (the final and 8 of the 2nd round matches), the team having to travel from one country to another had one more recovery day after their previous match than their opponents. The 3rd, place play off was the only match where one of the teams had to change countries and have a day less to recover from their previous match than their opponents. Domestic tournaments can also be altered to benefit national teams preparing for international competitions. For example, the English domestic soccer season will finish earlier than usual in 2006 to give the England World Cup squad a 4 week period between the domestic season and the 2006 FIFA World Cup.

The All-Ireland Gaelic Football Championships

Gaelic football is one of the national sports of Ireland, a country of 4 provinces (Connaght, Leinster, Munster and Ulster). The All-Ireland Gaelic Football Championship is contested by 33 teams (teams representing all of the 32 counties of Ireland except Kilkenny as well as London and New York). Before 2001, the All-Ireland Gaelic Football Championship was arranged on a knockout basis with the 4 provincial champions (London and New York competing in the Connaght Championship) meeting in the semi-finals. The 33 teams competing in the tournament are not divided equally among the 4 provinces. Figure 1 illustrates the structure of the tournament prior to 2001. In Ulster, there are 9 teams which necessitated a preliminary round of 1 match prior to the Ulster quarter-finals. Leinster required a preliminary round of 3 matches prior to the Leinster quarter-finals because there are 11 teams. Connaght and Munster have less than 8 teams in their provincial championships and, therefore, preliminary rounds were not required. Furthermore, some teams in Connaght and Munster received byes into the provincial semi-finals. The tournament design prevented any more than one team from each province reaching the All-Ireland semi-finals.

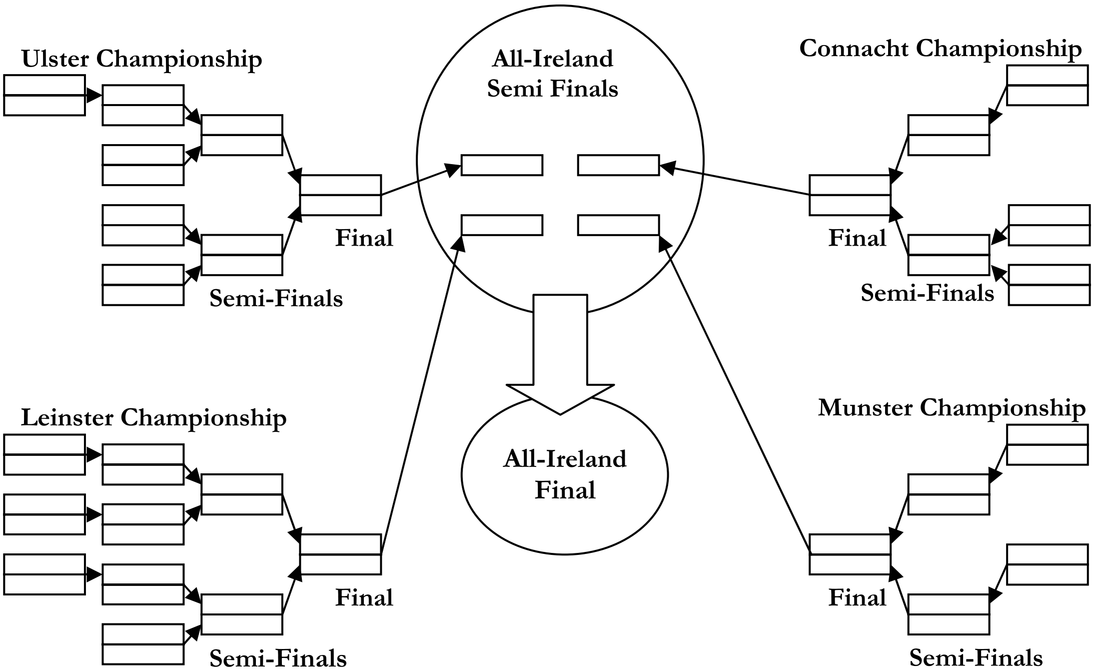

Figure 1. All-Ireland Gaelic Football Championships Pre-2001.

In 2001, the structure of the tournament was amended so as teams eliminated during the provincial stages would compete in a parallel knockout system referred to as the "back-door" system. This current structure of the tournament is illustrated in Figure 2. The provincial championships are contested as before, except that the 4 provincial champions enter the quarter-finals of the All-Ireland Championships rather than the semi-finals. Those teams knocked out of the provincial championships before the provincial finals contest the "back-door" competition from which 4 teams emerge. These 4 teams compete in play-offs with the 4 provincial runners up to determine the 4 teams to join the 4 provincial champions in the All-Ireland quarter-finals. Therefore, all teams other than the provincial champions need to be defeated twice to be eliminated from the All-Ireland Championships. The current tournament structure allows for the possibility of more than one team from a single province making the All-Ireland final. Indeed in 2003, there were 3 Ulster teams in the semi-finals and 2 Ulster teams in the final (Tyrone and Armagh).

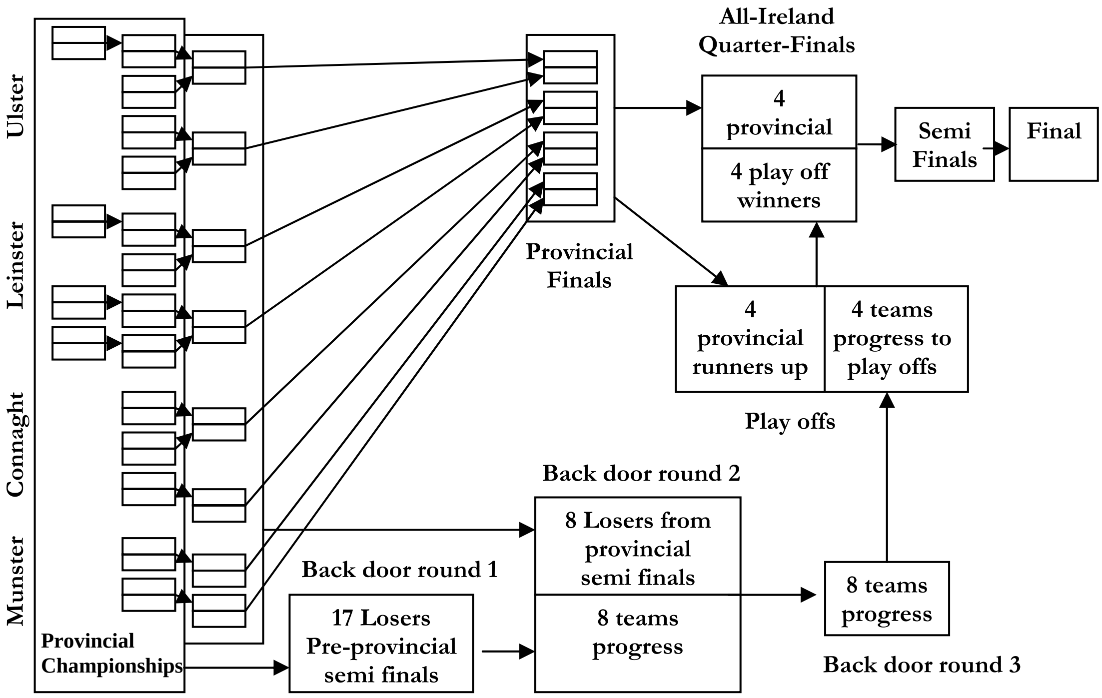

Figure 2. Current structure of the All-Ireland Gaelic Football Championships.

The characteristics to be investigated by the simulation studies done in the current investigation are (a) the strengths and (b) the provinces of the teams reaching the semi-finals and final as well as the teams winning the tournament. The first of these is a characteristic of a sports tournament of general interest to other sports. The province of the teams reaching the later stages of a tournament is an example of how simulation can be used to answer detailed individual questions relating to a specific tournament.

Methods

The simulation models used in the current study were based on a number of assumptions. The National Gaelic Football League is contested over the winter and spring and finishes before the All-Ireland Gaelic Football Championship takes place over the summer months. There are 4 divisions of 8 teams and each division operates as a round-robin tournament. It is assumed that a team's league division and placing within that division would be an indication of team strength for the All-Ireland Gaelic Football Championship to follow. For each simulated tournament, the distribution of teams from each province among the different National League divisions was randomised. This assumes that there are no traditionally dominant provinces or indeed traditionally dominant county teams. The probability of a team winning a match against a given opponent was assumed to be the same no matter what venue the match was played at. The probabilities used are arbitrary but still allow a relative comparison between alternative tournament designs. Stationarity and independence were also assumed. Stationarity means that within a simulated tournament, a team's strength remains constant while independence means that a team's chances of winning a match are not influenced by the outcomes of previous matches within the tournament or the need for replays.

Matlab 7.0.1 (MathWorks Inc, Natick, MA, USA) was used to program simulation systems for the current (including the "back door" system) and pre-2001 versions of the All-Ireland Gaelic Football Championships. All of the teams in the All-Ireland Gaelic Football Championships except New York compete in the All-Ireland League which is structured into 4 divisions of 8 teams (Divisions 1A, 1B, 2A and 2B). For the purpose of the current investigation an arbitrary function was used to relate the probability of a team winning a tie to the assumed strengths of the team and the opposing team. Team strengths of between 1 and 10 were assigned to each team with 10 representing the highest strength. The teams were allocated strengths according to Table 1.

Table 1. Assumed team strengths based on National League division.

Strength	Team(s)
10	Strongest team in Division 1A
9	2nd strongest team in Division 1A
8	3rd and 4th strongest teams in Division 1A
7	Weakest 4 teams in Division 1A
6	Strongest 4 teams in Division 1B
5	Weakest 4 teams in Division 1B
4	Strongest 4 teams in Division 2A
3	Weakest 4 teams in Division 2A
2	Strongest 4 teams in Division 2B
1	Weakest 4 teams in Division 2B as well as New York

The probability, p, of a team of strength, $s1$, winning a tie against a team of strength, $s2$, is given by equation (1). This ensured that in matches between teams of even strength, each team would have a probability of 0.5 of winning the tie. Where a team of strength 10 played a team of strength 1, it would have a probability of 0.95 of winning the tie.

$$p = 0.5 + (s1-s2)/20 \tag{1}$$

Each simulator ran the version of the tournament it represented 1000 times counting the number of champions, runners up and semi-finalists of each team strength as well as from each province. For each of the 1000 simulated tournaments, the simulator randomly distributed All-Ireland League divisional memberships (and hence team strengths) among all of the teams except New York who were always allocated a team strength of 1. This was done to reflect the fluctuating form of county teams over time. The simulators made any draws that were necessary at any stages of the tournaments using the random function of MatLab.

Results

Progression statistics were accumulated during the 1000 executions of each simulated tournament structure allowing different aspects of the tournament structures to be compared. Table 2 shows the team strengths of the 1000 simulated tournament winners, defeated finalists and defeated semi-finalists for the two tournament structures. In interpreting the figures, it is worth recalling that there is 1 team of strength 10, 1 of strength 9, 2 of strength 8, 5 of strength 1 and 4 of each other strength value within each simulated tournament. The median winners, runners up and losing semi-finalists for both tournament structures had strength values of 8, 7 and 6 respectively. However, the inter-quartile ranges for these 3 distributions were located higher for the current version of the tournament than for the pre-2001 version. A Mann Whitney U tests revealed that no significant difference in winning team strength under the pre-2001 and current versions of the tournament (z = 1.96, p = 0.050). However, Mann Whitney U tests revealed that stronger teams are runners up (z = 2.57, p = 0.010) and are losing semi-finalists (z = 4.47, p < 0.001) more under the current version of the tournament than under the pre-2001 version.

Table 2. Team strength of tournament winners, runners up and losing semi-finalists.

Tournament	Team Strength									
	1	2	3	4	5	6	7	8	9	10
Pre-2001										
Winner	4	11	27	33	80	139	189	169	124	224
Runners Up	16	32	50	97	111	182	201	137	86	88
Losing Semi-finalists	102	103	152	183	260	303	386	246	134	131
Current (Back Door)										
Winner	3	9	21	35	63	108	203	190	131	237
Runners Up	7	17	49	70	115	177	221	163	83	98
Losing Semi-finalists	50	72	123	180	241	344	412	273	150	155

Table 3. Provinces of tournament winners, runners up and losing semi-finalists.

Tournament	Province				χ^2_3, p
	Ulster	Connacht	Leinster	Munster	
Pre-2001					
Champions	255	236	260	249	44.8, p<0.001
Runners Up	254	226	274	246	35.6, p<0.001
Semi-Finalists	491	538	466	505	151.3, p<0.001
Current ("Back Door")					
Champions	262	221	292	225	16.2, p=0.001
Runners Up	274	228	287	211	12.3, p=0.006
Semi-Finalists	507	461	561	561	54.3, p<0.001
Expected					
Champions	272.7	212.1	333.3	181.8	N/A
Runners Up	272.7	212.1	333.3	181.8	N/A
Semi-Finalists	545.5	424.2	666.7	363.6	N/A

With 11 teams out of 33 from Leinster, one would expect one third of all tournaments to be won by teams from Leinster if the tournament structure generated winners that represented the provinces proportionately. Table 3 shows the expected number of winners, runners up and semi-finalists from each province based on the numbers of teams in those provinces as well as those that occurred during the two sets of 1000 simulated tournaments. Chi square goodness of fit tests revealed significant differences between the observed counts and expected counts for both tournament structures. However, the current tournament structure represented the provinces more proportionately in the semi-finals and final than the pre-2001 version. Table 3 shows that teams from Ulster and Leinster are closer to the expected frequencies in the current version of the tournament than in the pre-2001 version.

Discussion

The results of the simulation study show that significantly stronger teams make the semi-finals and final of the All-Ireland Championship under the current version of the tournament than under pre-2001 conditions. Therefore, the current investigation has provided some support for the decision to introduce the "back-door" system. This agrees with previous research that showed that double knockout tournaments of 8 teams ranked them more accurately according to their ability than traditional knockout tournaments (McGarry and Schutz, 1997). The current study has revealed no significant difference between the pre-2001 and current versions of the tournament for the strength of the winning team. This similarity in winning team but difference in losing finalists and semi-finalists seen between the two tournament structures agrees with some aspects of previous research. For example, McGarry (1998) describes analyses done by Wiorkowski (1972, cited in McGarry, 1998) that suggested the traditional knockout structure does an injustice to the second best team and by Fox (1973) that suggested that the double knockout structure does an injustice to the third best team. These issues should not be of too much concern to the Gaelic Athletic Association (GAA), the governing body of Gaelic games including Gaelic football, as there is a National League organised as a round robin tournament as well as the All-Ireland Championship.

The current investigation suggests that there is still an outstanding issue for the GAA relating to the fairness of the tournament structure to teams from different provinces.
The distribution of winners, runners up and losing semi-finalists among the four different provinces is still significantly different to the expected distribution based on the number of teams within each province. Leinster and, to a lesser extent, Ulster are disadvantaged. This could be because there is more chance of strong teams from these provinces being beaten in larger provincial championships and being drawn against each other during the "back-door" competition. A team from Munster, on the other hand, could make the All-Ireland championship final in 4 matches. Teams from Ulster or Leinster that are drawn in the preliminary round and needing to use the back door route will require 8 matches to reach the All-Ireland championship final.

In making these assessments, one must recognise the limitations of the assumptions made in the current investigation. Stationarity and independence as described by McGarry (1998) are assumed in the current simulation study. Stationarity assumes that the probability of a team winning a match against the same opponent will be constant over time. There are reasons why this assumption may be unrealistic. Venue effects are now well recognised in sport (Corneya and Carron, 1992) and the explanations of distance travelled (Brown Jr *et al*., 2002), facility familiarity (Loughead *et al*., 2003) and crowd noise (Nevill *et al*., 2002) can be expected to effect Gaelic footballers' performances. The strength of a team can improve as players join or return from injury or decline as players leave or become injured. Changes in team management and coaching can be beneficial or detrimental to team performance (Audas *et al*., 1997), challenging the assumption of stationarity.

Independence is an assumption that the outcome of a match is unrelated to the outcome of previous matches. This may not be a realistic assumption, as a team that has enjoyed easier victories in the previous rounds of the tournament may be better prepared for a match than an opposing team that has expended greater effort during the previous rounds in closer matches. The influence of additional effort reducing the chance of winning in a subsequent match has been observed in Grand Slam singles tennis. The chances of winning a tennis match are reduced if too many sets are required in the matches played in the preceding two rounds (O'Donoghue, 2004). Other challenges to the assumption of independence come from international soccer. There have been occasions in the past where two teams played a pool match in an international knowing that a certain result would allow both teams to qualify for the next stage of the tournament. In the 1982 FIFA World Cup, for example, a victory for West Germany over Austria by a score of 1-0 would allow both teams to qualify ahead of Algeria. Whether this knowledge influenced the style of play of the two teams in the match is a matter of debate. More recent FIFA World Cups have required the last two matches in any pool of 4 teams to be played simultaneously. Where teams are playing in several tournaments simultaneously, one may become more critical to the team than the others. This may effect team selection, commitment and ultimately the chances of winning.

Despite the limitations of the assumptions of the current simulations, the example still forms a useful illustration of the type of information that can be produced when probabilities of match outcomes are better understood. Furthermore, it is a useful example of how simulation can be used to provide information about tournament structures that can benefit the decisions made by tournament designers and organisers. It is possible to provide an analytical solution to a probabilistic model of a tournament structure. However, such analysis can become very complex. Research into the probability of winning tennis matches provides a good example of this. There are some models that use the same assumed probability of the superior player winning a point in serving games and receiving games (Carter Jr and Crews, 1974; Croucher, 1982; Fischer, 1980; Schutz, 1970). Pollard's (1983) model uses distinct probabilities for different players' service games and is much more complex in expression as a consequence. Although this paper has compared 2 tournament structures after a decision has been made to change the tournament structure, simulation could be used to compare alternative tournament structures during the development of new tournament designs. This can be done flexibly allowing experimentation with specific proposed tournament features. This allows potential problems with tournament designs to be identified and improves the quality of decisions relating to developments in sports tournaments. The ability of simulation to model and provide information about systems being developed gives it wider applications in sport. These include simulation of matches where different strategies are applied, simulating the impact of alterations to sports equipment as well as economic models related to sports marketing and audiences.

Conclusions

The current investigation has shown the value of simulation to help decision making in sport. The example simulations show how the approach could assist those designing sports tournaments. Indeed, there are alternative structures to the All-Ireland Gaelic football championship that can be analysed and compared with the pre-2001 and current formats analysed here. The simulation algorithms can be augmented with statistical gathering routines to analyse many different aspects of interest such as the chances of a team winning the tournament through the "back-door" route. This ability to provide detailed specific information about systems being simulated is of benefit to simulation exercises in other areas of sport.

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Dynamic Simulation of Performance Development: Prediction and Optimal Scheduling

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Abstract

Development of performance output depends on load input in complex ways. Two central aims of training and performance analysis are optimizing the training effort and predicting the training result.
The *Per*formance *Pot*ential Metamodel *PerPot* models the interaction between training input and performance output in adaptive physiologic processes by means of antagonistic dynamics. This means that training input causes two concurrent effects – namely the performance improving response flow and the performance reducing strain flow. Depending on the respective delays with which these flows become effective, a training input can cause positive or negative results in the initial phase.
In the phase of calibration those delay values have to be deduced from the original load and performance profiles. Once calculated, the delay values not only allow for simulating given performance values but also for predicting future ones.
As will be demonstrated, prediction works surprisingly well and therefore can be used for developing optimal schedules. Moreover, comparing different schedules can help for understanding how the performance output changes if the load profile is changed. Doing this by means of simulation saves time and is careful with the athlete.

KEYWORDS: PERFORMANCE, PREDICTION, SCHEDULING

Introduction

Development of performance output depends on load input in different and specific ways. On the one hand, the kinds of load and performance are important. E.g. in case of running, load could be speed or duration, and performance could be heart rate or haemoglobin concentration. On the other hand, the time orientation is important, e.g. if a short-term (one contest or training unit), a medium-term (weekly or monthly training schedule), or a long-term analysis is of interest.
Two central aims of training and performance analysis are optimizing the training effort and predicting the training result. In order to reach those aims, models are useful, which help for simulating the interaction between load input and performance – independent of their specific kinds and independent on the time-orientation.
Our working group has been developing the metamodel PerPot (Performance Potential, see Perl, 2004), which is independent of the particular kinds of load and performance as well as of the meaning of time units. It can be adapted to arbitrary athletes, disciplines, and time

orientations. The reason is that PerPot on a very high level of abstraction simulates the main antagonistic system dynamics of load-performance-interaction.

The result is that PerPot can be used not only for analysing recorded values but also for simulating future development. Therefore, PerPot is able to predict load-performance-interaction and so can be used for scheduling optimal training planes.

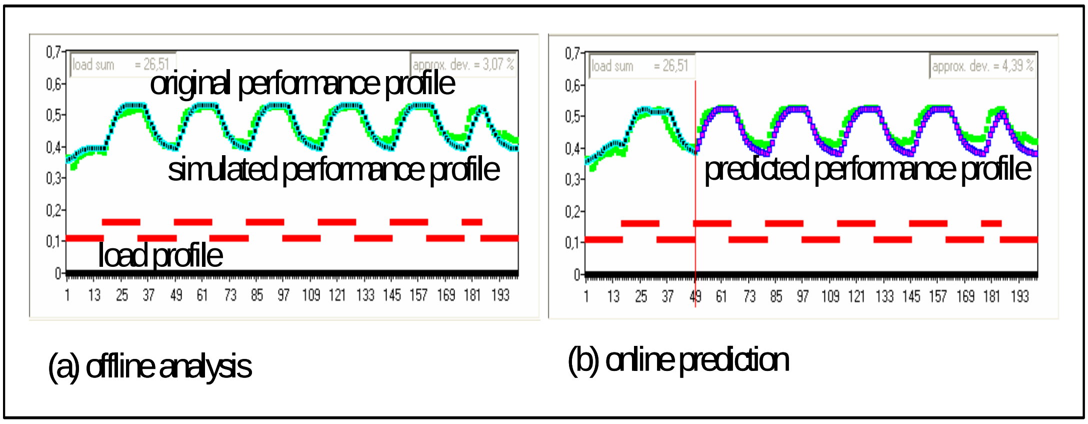

Figure 1: Offline load-performance-analysis (a) compared to online performance-prediction (b).

The graphics in Figure 1 demonstrate how PerPot analyses and simulates known data, and how, based on the temporary results, it predicts future development: The load is measured by speed, while the performance is measured by heart rate, both normalized to the vertical scale from 0 to 1. The time units mean "15 seconds". In graphic (a), the simulated performance profile (blue resp. dark grey dotted line) is calculated using the complete information from all 200 time steps. In graphic (b), from only the first 50 pairs of data the following 150 performance values are predicted (violet resp. dark grey dotted line). The simulated and the predicted profiles are almost identical. The systematically increasing deviations (compared to the original performance profiles) are caused by decreasing condition of the runner. This way, additional information can be obtained from simulation and can be used for load schedule optimization.

The PerPot-Concept

The *Per*formance *Pot*ential Metamodel *PerPot* models the interaction between load or training input and performance output in adaptive physiologic processes by means of antagonistic dynamics. This means that load input causes two concurrent effects – namely the performance improving response flow and the performance reducing strain flow. Depending on the respective delays with which these flows become effective, a training input can cause positive or negative results in the initial phase.

An example for such dynamics is given by interactions of organs or components of an organism, which produce and transport substances with certain delays and so change the organism's state.

Basic antagonistic structure

Modelling the antagonistic concept in an abstract way means to complete the external level of load input and performance output (PP: performance potential) by two internal buffers that represent the organic components: the strain potential SP and the response potential RP (see Figure 2). The main point is that the load input does not directly influence the performance potential but feeds the internal buffers SP and RP in identical ways, which then by delayed flows change the performance potential: The negative strain flow from SP to PP decreases the level of performance, while the positive response flow from RP to PP increases the level of performance. The interaction of those flows is characterized by the delays: If the delay DS of the strain flow is smaller than the delay DR of the response flow then the load input first causes a reduction of performance, which only later can be compensated by the positive response flow. One result can be super-compensation, as is shown in Figure 2. If DS is greater than DR then the positive response effect is faster, causing an immediate increase of performance, which later can be reduced and stabilized by the negative strain flow effects.

It should be noticed that the delay values in a first approximate view of the model can be understood as constant model parameters. In so far the delay parameters characterize the athlete's state or shape in the context of the specific discipline. However, practical experience show that those parameters change depending on states and events like fatigue, breaks, sickness, or vacation. In turn, as will be discussed later on, time-depending delay profiles allow for analyses of changing athlete states.

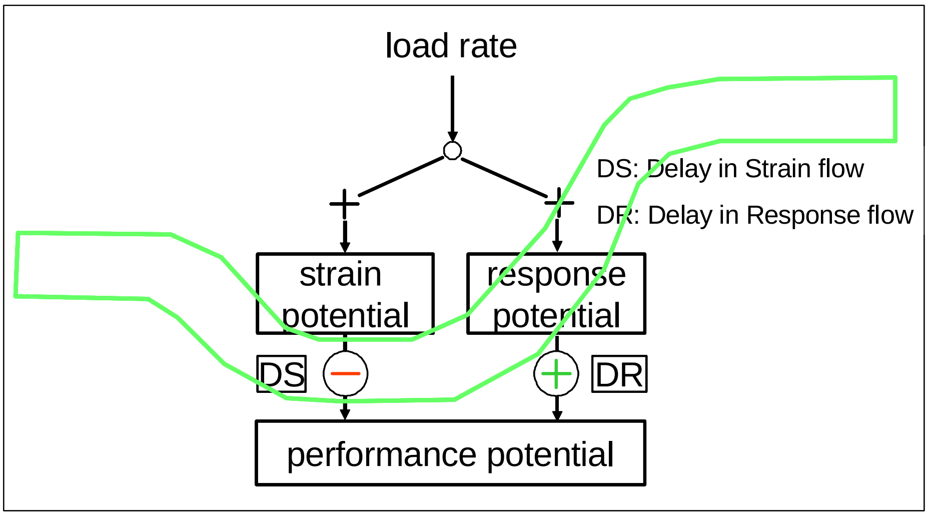

Figure 2: Basic antagonistic structure of PerPot. Green graphic: super-compensation in case of DS < DR

More information, in particular regarding additional aspects like reserve, overload, and atrophy, can be obtained from Perl & Mester (2001), Perl (2002) and Perl (2004 a). The role of time scales and delay parameters in more detail is dealt with in Perl (2004 b).

Performance prediction

In an initial phase of calibration the delay values have to be deduced from the original load and performance profiles. Consequently it can be asked how many past data are necessary to

calculate delay parameters, which not only allow for simulating the past performance values but also for predicting the future ones.
Figure 3 shows an example from running, where the red load profile indicates running speed on two alternating levels and the green performance profile indicates the heart rate in beats per second (both scales normalized to the maximum "1"; one time unit means 15 seconds).
It can be seen that 5 data seem not to be sufficient for a proper prediction (left graphic), while 25 data seem to fit rather well (right graphic). The truth is that the typical dynamic changes, e.g. from low to high and/or from high to low load, are necessary to give the model enough information about the characteristic adaptation behaviour.

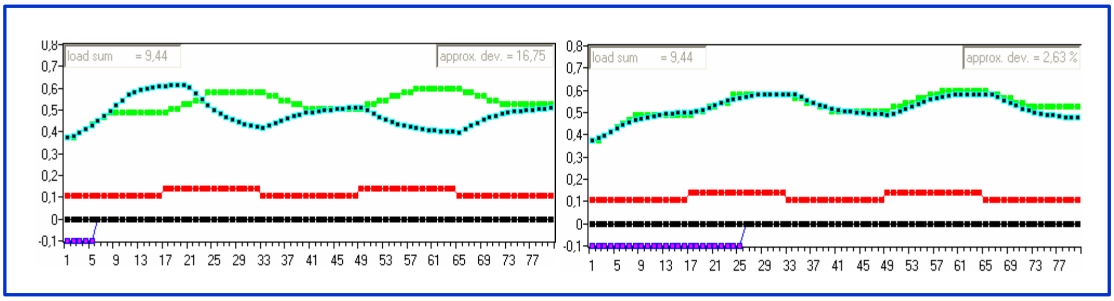

Figure 3: Original load profile (red), original performance profile (green), range of available information (violet), and simulated performance values (blue).

This method of prediction can be used for online adaptation: Every new pair of load and performance values can improve the adaptation of the delay values to the changing situation respectively to the changing status of the athlete and therefore can improve the prediction of future values corresponding to a scheduled load profile. Figure 4 demonstrates the time-depending process of online-prediction.

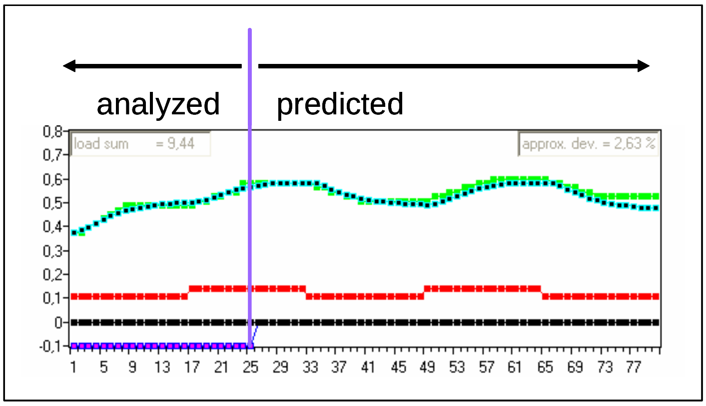

Figure 4: Original load profile (red), original performance profile (green), past time units (violet) indicating already available information, and simulated performance values (blue). The vertical line indicates the present time unit. Left from the present time all information is given for offline-analyses; right from the present time the simulated performance values are online-predicted, depending on the scheduled load profile and the analyzed delay values.

In Figure 5, for running and biking the respective offline-simulations are compared to the corresponding online-predictions. The vertical axes are normalized to a maximum of "1"; the time units are "15 seconds". It turns out that even for a time period of 50 minutes the online-prediction is nearly as good as the offline-analysis. In the example of biking, during the first 6 minutes there are some relevant deviations, which are caused by the lack of information typical for the initial phase.

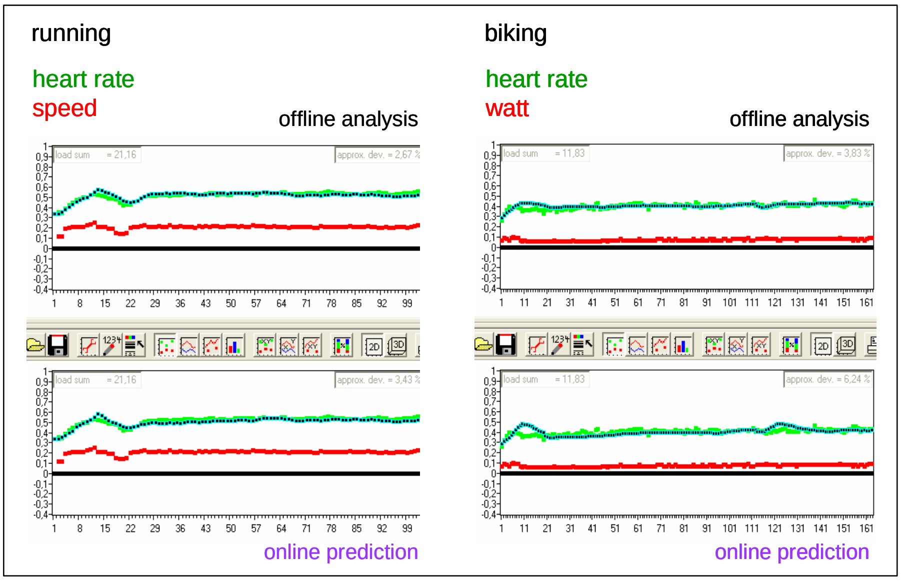

Figure 5: Offline analysis and online prediction compared for running and biking.

In the example of ergometer running in Figure 6, the behaviour can be analyzed more systematically using alternating speeds and more precise speed values. The obvious result is a relevant deviation at the end of the time range, which has nothing to do with a lack of information as in the starting phase in biking from Figure 5.

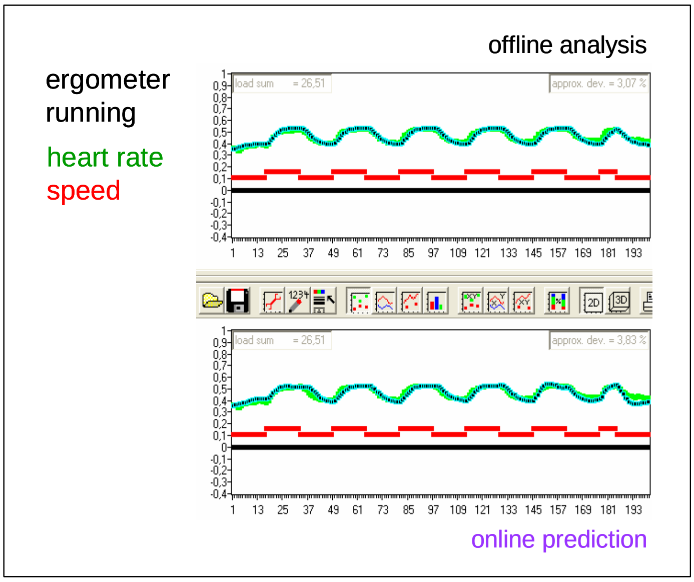

Figure 6: Offline analysis and online prediction compared for ergometer running.

Deeper analysis shows that the deviation between original and simulated performance in Figure 6 is caused by a change of the delay values: As has been mentioned above, the delay values can change depending on the athlete's changing state or shape. In turn, increasing deviations between original and simulated performance values can indicate changing delay values caused by a changing athlete's state. Figure 7 and Figure 8 demonstrate a typical

PerPot-based analysis of such a time-depending change of adaptation: The left graphic in Figure 7 shows the example of Figure 4 with the marked deviation in the final phase, predicted after 25 time units. The right graphic shows that even if all information is available the deviation still holds. A closer look additionally shows that there is a systematic deviation over the whole period: While in the first half the predicted values are too high (green mark), in the second half the predicted values tend more and more to be too low (red mark).

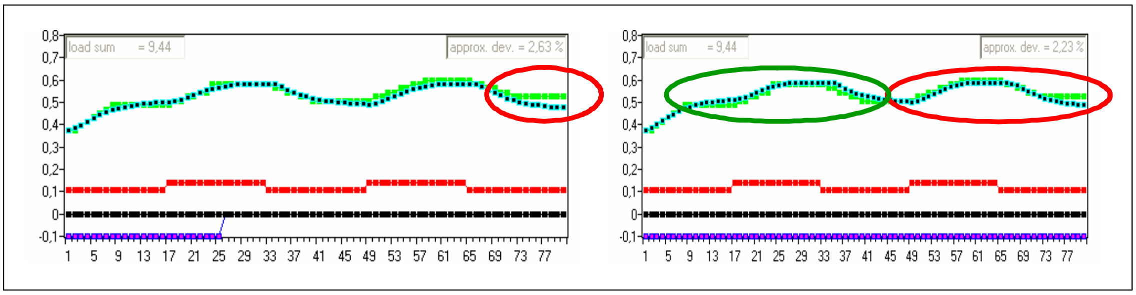

Figure 7: Deviation of prediction in the final phase (left graphic) and systematic deviation between simulated and original performance values over the whole period (right graphic): In the green marked period the simulated values are too high; in the red marked periods the simulated values are too low.

A PerPot-based analysis shows (see Figure 8) that the assumption of a constant delay value "DS=4.5" does not hold. Instead, the mean value of DS changes from 4.3 in the beginning to 4.9 in the end. This means that in the beginning the assumed constant value of DS is greater than the true one – indicating an apparently worse shape and causing a higher heart rate output – while in the end the assumed constant value of DS is smaller than the true one – indicating an apparently better shape and causing a lower heart rate output.

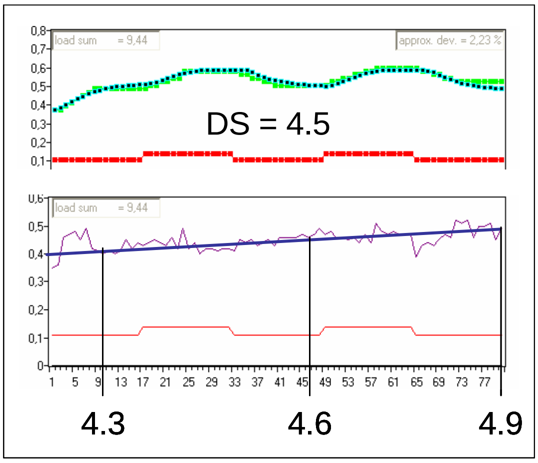

Figure 8: The time depending change of the true values of the strain delay DS (below) and its consequences for the deviations between simulated and original performance values (above).

Taking the online-calibrated DS-values from Figure 8 for prediction can improve the precision of prediction significantly. As is demonstrated in Figure 9, the deviation is reduced from 2.2% to 1.5%, and in particular the fatigue phase of the runner is predicted much better.

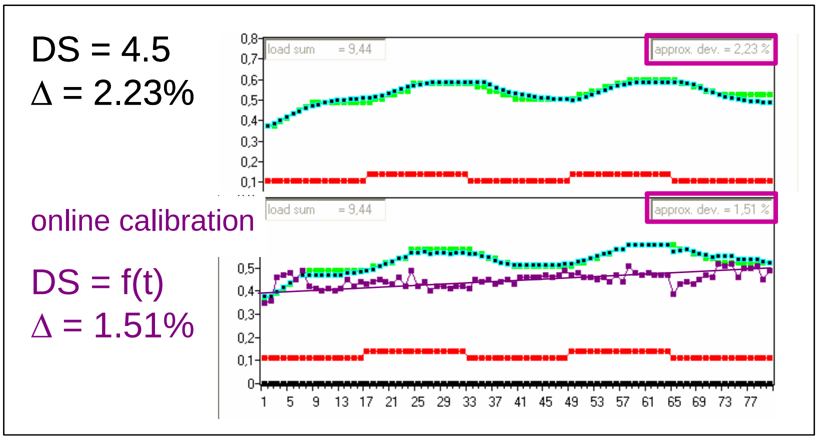

Figure 9: Offline analysis and online prediction compared for ergometer running, using online-calibrated DS-values.

Load and performance scheduling

Since prediction seems to work surprisingly well, it can be used for developing optimal schedules – i.e. to use predicted behaviour in order to adjust load profiles optimally to intended performance profiles. Moreover, comparing different schedules can help for understanding how the performance output changes if the load profile is changed. Doing this by means of simulation saves time and is careful with the athlete.

Two main types of scheduling can be distinguished – short-term scheduling in case of single events or training units like the examples of running and biking from above and long-term scheduling, where the training plane and the load distribution over a season is of interest.

Short-term scheduling

In the case of short-term scheduling, the connection between delay and state can be used for detecting striking features and avoiding negative situations. Moreover, as is shown in Figure 10, data recording, analysis and controlling (in principle) can be done online, where the recorded data are continuously analysed and compared with the prepared schedule. The result is fed back to the athlete and helps for controlling his activities.

Assume as an exemplary scenario that the runner has a standard DS-value that characterizes her normal state and she follows an optimal schedule that tells her which speed to run at which time, in order to have the heart rate in the specified range.

(a) A predicted unexpected sudden deviation between scheduled and original performance normally is not caused by a change of the delay values and therefore indicates either a relevant deviation between scheduled and original load or a serious kind of threading break down. In the first case the schedule can be online adjusted in order to avoid under- or over-training. In the second case the information can stop the runner and so avoid serious problems. In both cases immediate feedback helps for online watching and controlling.

(b) A slowly and systematically increasing deviation between original and predicted performance profiles normally means a change of delay values and therefore informs the athlete about a corresponding change of her state, caused for instance by fatigue or sickness.

This fast feedback on the one hand tells the athlete to be more careful and on the other hand can be used for online-adjusting the schedule.

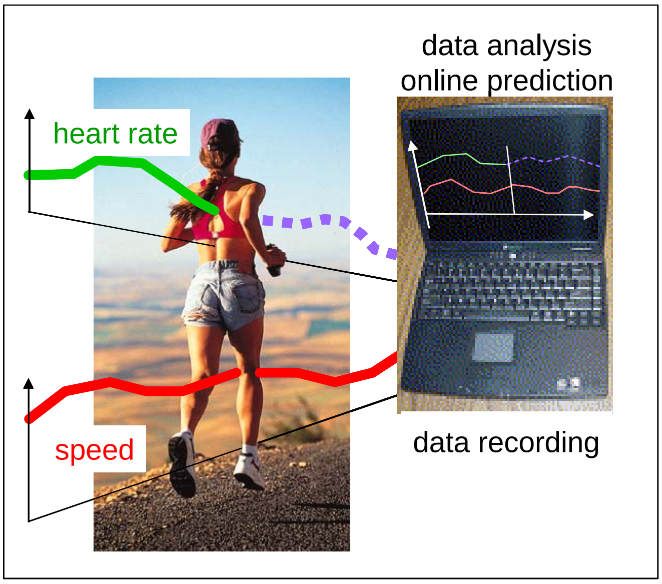

Figure 10: Online recording, analysis and prediction of training data.

Long-term scheduling

In the case of long-term scheduling not a single training unit or event but the optimal distribution of load over the season in order to maximize the results of the athlete is of importance.

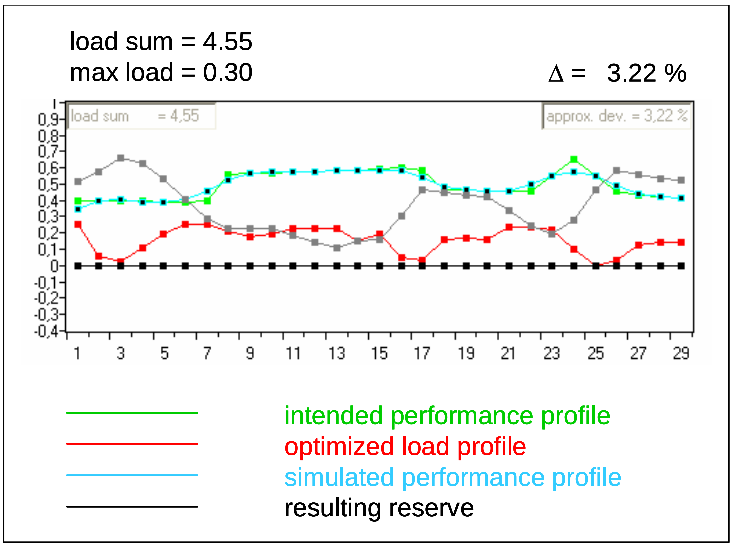

Figure 11: Intended performance profile, modelling a high level season from "7" to "17", followed by a recovery break from "18" to "23", and finally closed by a main event at "24".

In the example from Figure 11 the intended performance profile has been met rather perfectly by a PerPot-generated scheduling. The load profile is smooth and with low values of load maximum and load sum. The reserve, which is indicating the level of not being exhausted, is comparably high.

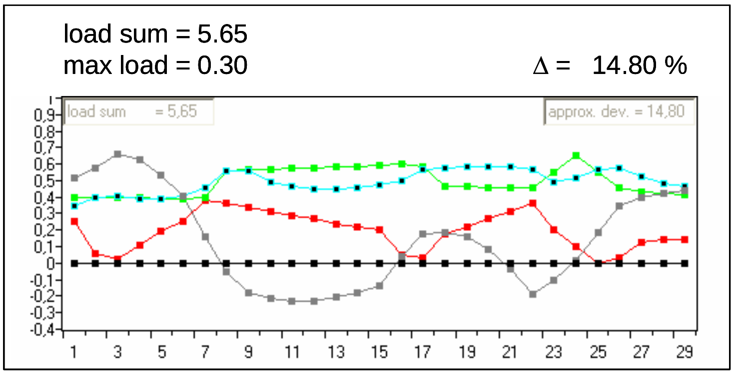

Figure 12: Manually "improved" schedule, where the increased load reduces the performance.

In contrast, Figure 12 shows an "improvement" of the schedule from Figure 11: The season starts with a phase of overloading in order to fast increasing the performance. Also the main event is given some additional load to make sure the athlete is well prepared. The results, however, are quite different from the expectations, as Figure 12 shows: The overload reduces the performance, and the later increase of performance is rather a result of recovery than of training.

Moreover, the load sum has increased by 24%, the deviation between intended and scheduled performance profile has increased by factor 4.6, and the reserve profile indicates that the athlete would be beyond a healthy situation. As mentioned above, this example makes plain that a simulative scheduling can help not only for finding optimal load profiles but also for saving the athlete's health.

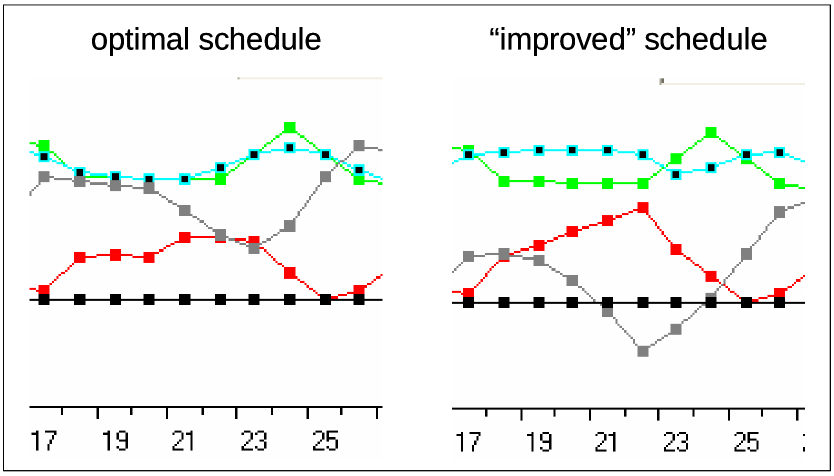

Figure 13: Zoom into the top event phase of Figure 12.

Zooming into the "main event" of Figure 12 shows a typical situation in preparing a top of the season (see Figure 13): In order to make sure that the athlete is quite on the top event of his performance, the load is increased a couple of weeks before – causing, however, an overload-driven performance reduction and a delayed recovery. The effect is that exactly at the point of competition the performance is down, while a bit later the athlete is of good shape again. This simulation reflects a lot of examples from athletes who were "sub-optimally" prepared for key events like Olympic Games or World Championships.

Conclusion

The PerPot-approach can help for a model-based prediction of the load-depending development of performance. Moreover, it can make transparent how the interaction between load and performance works and what the role and meaning of delays are. In particular it enables for checking state and shape of the athlete combined with optimal adjusting the training schedule to the athlete. The result not only is an improvement of the performance. Additionally, the load can be reduced, which can help for avoiding critical or unhealthy situations.

The PerPot-software offers a number of components for analysing load, performance, and delay data, predicting performance behaviour and development, and scheduling optimal training planes.

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A Sports Oriented Concept for Developing Multimedia Learning and Teaching Materials

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Abstract

In the years 2001-2003 an internet-based information system was developed to assist students in learning and comprehending theoretical basics and concepts of sport scientific disciplines (biomechanics, physiology, psychology, etc.). In contrast to many other multimedia systems used as eLearning tools in sport science, the starting points are sports and not disciplines. Questions related to these sports are asked and then answered from the perspective of sport scientific disciplines in a highly interdisciplinary way. Not least because of positive experiences with students, who participated in the project, the development of multimedia learning and teaching materials has been integrated into the education program. As part of their diploma works, students are encouraged to create multimedia software. Again, the systems to be developed focus on sports, what appears to have a high motivational effect on the students. Throughout the last years very impressive packages have been developed. As a consequence of this process, the amount of multimedia modules and submodules for different sports is continuously growing. A standardized, structured framework is therefore under development. Modules and submodules are organized in the form of a matrix of sports and sport scientific disciplines. The overall system is based on an open source based content management system simplifying the integration of all information assets.

KEY WORDS: MULTIMEDIA, EDUCATION, E-LEARNING, INFORMATION SYSTEM, WEB BASED EDUCATION, WEB BASED TRAINING

Introduction

Due to increasing advancements in computers and electronic media the potential for quality education has been elevated with the appearance of innovative instructional methods employing multimedia equipment and resources. Currently available software authoring packages such as Matchware Mediator®, Macromedia Authorware® or Macromedia Director® offer numerous options for the development of educational applications. Graphic, video, sound, animation, text and hyperlinks can easily be integrated. Throughout the last years increasing efforts in developing and using multimedia based courses and materials can be observed (Katz, 2003; Sorrention, 2001; Igel & Daugs, 2005; Wiksten, Spanjer & LaMaster, 2002). Multimedia eLearning systems have particularly been developed for sport disciplines or for sub fields of sport science such as sports biomechanics (Tavi, Sholev & Ayalon, 1992; Schleihauf, 2001; Baltzopoulos & Papadopoulos, 2001). Interdisciplinary solutions have been an exception. Projects based on such an approach have therefore been initiated. Systems, which allow users to study sport scientific interdisciplinary were developed and will be presented in the sequel.

Developments

SpInSy

SpInSy – Sport Scientific Information System – was funded from the initiative "New Media in Teaching at Universities and Colleges of Higher Education" of the Austrian Federal Ministry for Education, Science and Culture. Project partners were the Faculty of Human and Social Sciences (University of Vienna) and the Faculty of Fine Arts (University of Salzburg) as parent organizational units of the departments of Sport Science involved. The total project period was two years (October 2001 - September 2003). The aim of the project was the development of internet based multimedia modules enabling users to learn sport science interdisciplinarily.

Based on four selected sports (Alpine skiing, tennis, running, long jump and soccer) SpInSy presents abstract theoretical concepts of different sub fields of sport science (mainly from natural science) (Baca & Eder, 2002) to assist students in learning and comprehending theoretical basics and concepts of sport scientific disciplines (biomechanics, physiology, psychology, etc.). In contrast to many other multimedia systems used as eLearning tools in sport science, the entry points of SpInSy are sports. Questions related to these sports are asked and then answered from the perspective of sport scientific disciplines in a highly interdisciplinary way. Students work with these modules in parallel and complementary to traditional lectures.

SpInSy shall stimulate the critical, networked and holistic thinking and encourage the intra- and interdisciplinary discussion. Because of the practical examples given, the theoretical connections and overlappings of the sport scientific sub fields become more transparent. Through the use of an explorative learning concept the learners take an active role in discovering and absorbing knowledge on their own. The material is structured into small and logically interrelated pieces. The learners may choose their own passage; they are able to interact within the environment and to explore certain problems. It is possible to navigate selectively through a closely knit network of knowledge modules. This concept supports the free investigation of complex contents. The users themselves are responsible for the success of the learning process.

Multimedia elements complement the theoretical information resulting in a modern teaching aid with interactive experiments and with exercises. Simulation components allow users to take an active part in working with the product. Questions of different kind and degree of difficulty are integrated in order to enable learners and teachers to control the knowledge acquired. Cognitive and motor tasks are included to gain a better understanding of the principles of motion. Observation tasks, for example, are provided for judging motions.

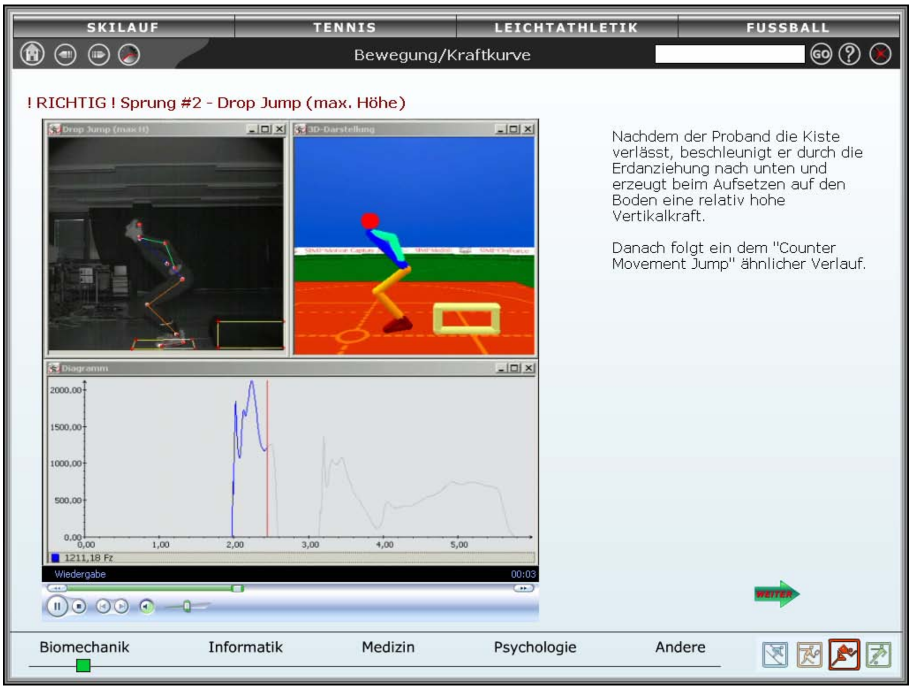


Figure 1. Biomechanics in SpInSy – Video of a drop jump and animation of vertical ground reaction forces.

Great emphasis has been put on aspects of software ergonomics and the design of the human computer interface. A standardized navigation system and a consistent toolbar have been developed for all modules. Help, history and search menus have been included and can be accessed whenever desired. A glossary of technical terms is integrated. Highlighted words within the text serve as links to explanations.
Selected frames of SpInSy are shown in Figures 1, 2 and 3.

Figure 2. Computer assisted game analysis in SpInSy – Systems and methods applied to soccer.

The main target group are students of sport science and physical education. Other users of the system are graduates of these studies, people interested in further education or interested in the theory of sport, coaches and members of sport associations

A cross-platform approach was a major criterion for selecting the development environment. Beside an internet based solution a CD-ROM version was also realized.

In order to satisfy these requirements the authoring system (Macromedia) Authorware® (6.0) has been selected. Authorware is a system, which makes it easy to realize multimedia applications via graphic programming.

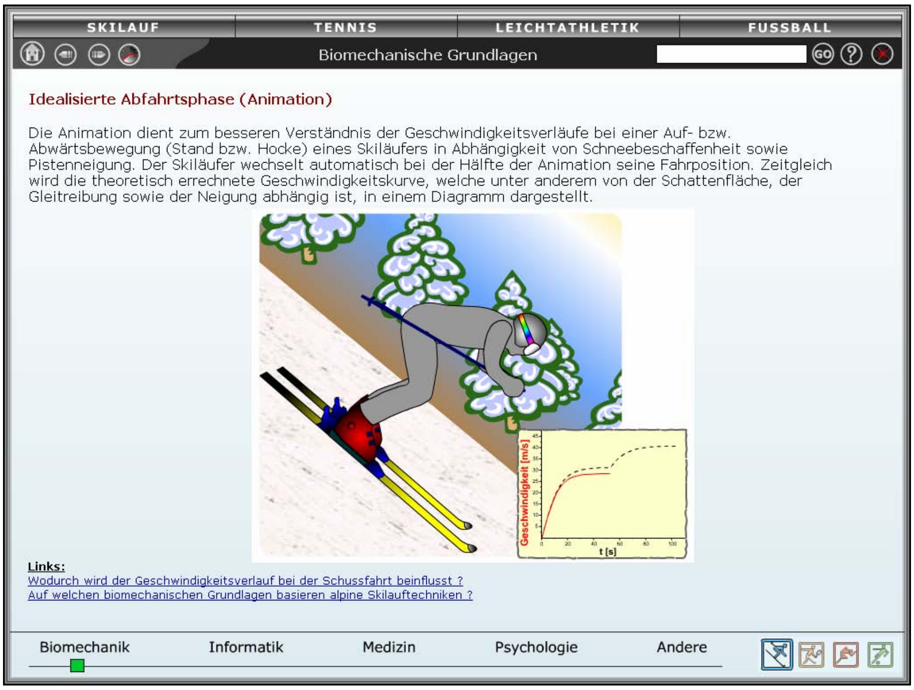
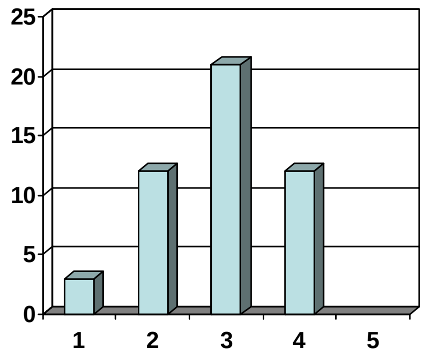


Figure 3. Simulation in SpInSy – Downhill race. The user may specify slope angle, posture of skier and friction parameters.

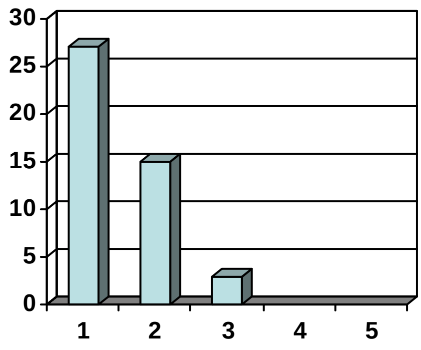
Some animations have been generated using the features of Authorware®, more complex animations have been produced in Macromedia Flash MX® resp. Curious Labs Poser® 4.0 (character animations) and than imported into Authorware®.

From the students' feedback we conclude that SpInSy is helpful to better understand the practical relevance of sport scientific disciplines.

An online questionnaire was developed to evaluate SpInSy. Beside of usability aspects questions regarding the comparison of the system to traditional teaching methods were included. Only students in at least the third year of their studies were asked to fill in the questionnaire. It was expected that these students should be better able to compare conventional teaching methods to eLearning. 45 students answered the questionnaire, using a scale from 1 (best) to 5 (worst). The distribution of answers for two selected questions shown in Figure 4 indicates that the primary goal of the project, to develop materials to be used supplementary to traditional teaching methods, has been reached (right diagram). Moreover, it shows that students do not prefer the eLearning materials to conventional lectures/courses (left diagram). SpInSy appears to be well suitable to be used in a blended learning environment.



Compared to lectures I can learn more effective using SpInSy



SpInSy is a good supplement to traditional learning methods

Figure 4. Evaluation of SpInSy – Scale from 1 to 5, 1 best; absolute values.

Following a blended learning approach the modules are presently used as accompanying and complementary materials within the studying process. A formal integration into the curricula is intended taking the interdisciplinarity of SpInSy into consideration. ECTS credits shall be assigned.

Integration of SpInSy into the Curriculum

The curriculum in sport science and physical education will undergo changes due to the availability of eLearning components. This will affect not only aspects of organization, but also alter established modes of knowledge transfer. Interlinked courses, for example, which provide students with the opportunity to bring together ideas, methods and approaches from different sub fields of sport science, can be developed more easily.
We aim to embed SpInSy and related modules into a course system following the Bologna model (cf. CRE, 2000) allocating credit points for both traditional and eModules (Figures 5 and 6).

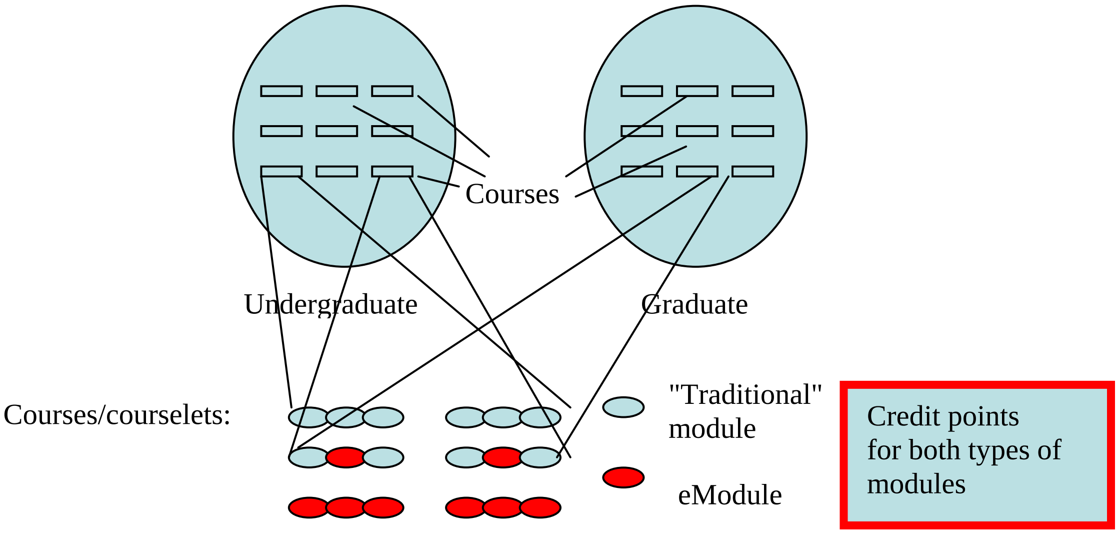


Figure 5. Example of a credit point system in an undergraduate/graduate course system (Bologna model). Adapted from Stucki, 2001.

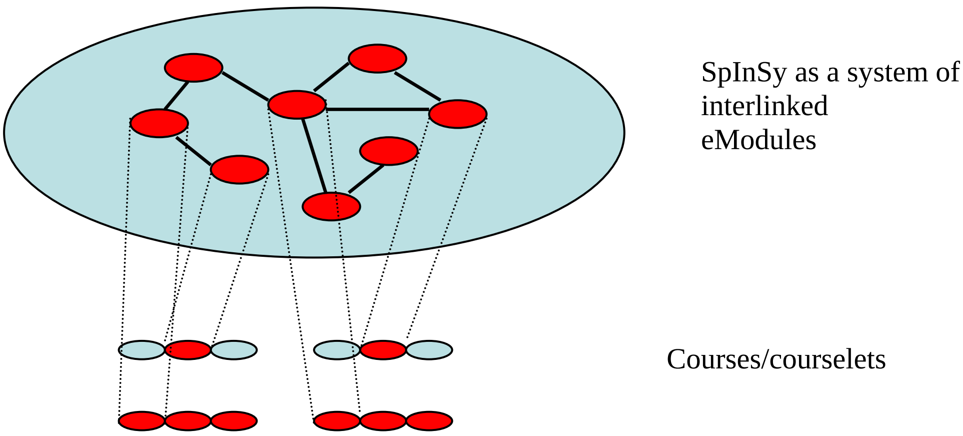


Figure 6. Embedding SpInSy into courses.

The interdisciplinarity of SpInSy allows a multiple use in different courses and courselets.

Master theses

Not least because of positive experiences with students, who participated in the project SpInSy, the development of multimedia learning and teaching materials has been integrated into the education program. As part of their diploma works, students are encouraged to create multimedia software. Again, the systems to be developed focus on sports, what appears to have a high motivational effect on the students. Experts in the respective sports are consulted in order to assure the quality of the materials.

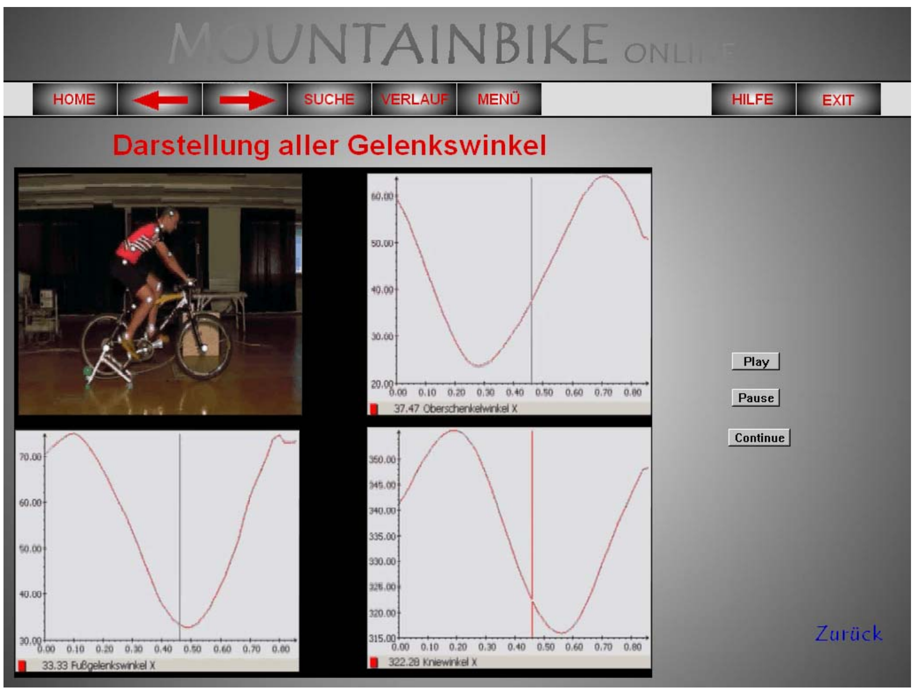


Figure 7. Video and animation to illustrate kinematic parameters in mountain biking (Gabler, 2004).

Throughout the last years very impressive packages have been developed dealing with snowboarding, Alpine skiing, mountain biking, running, Nordic walking, crawl swimming, inline skating, tennis, horse riding, beach volleyball, volleyball and long jump. Selected screenshots are shown in Figures 7 – 10. The development of further systems is in progress.

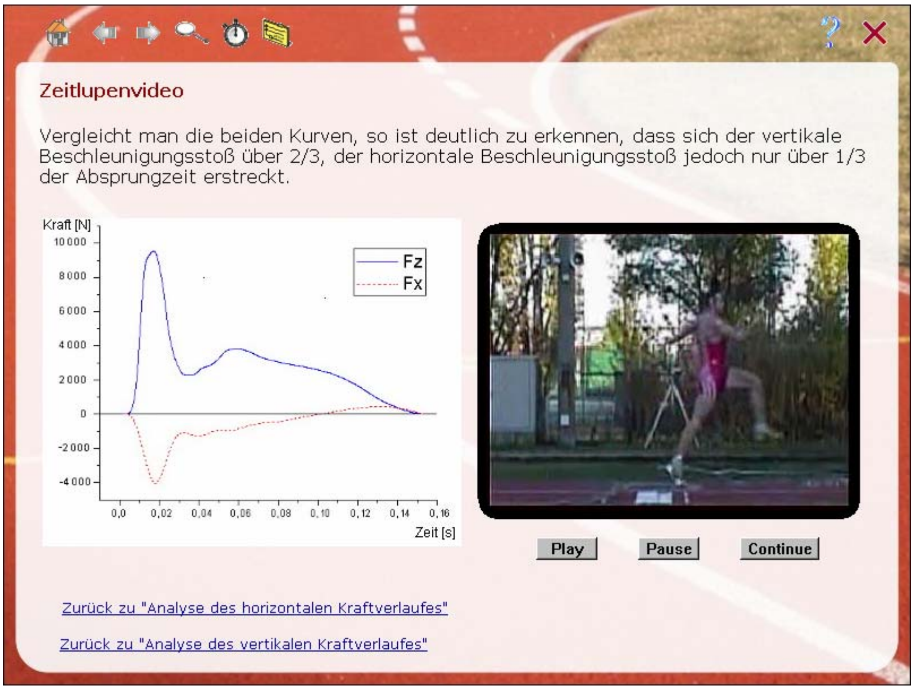


Figure 8. Highspeed video and animation of vertical ground reaction forces at takeoff in the long jump (Wiesinger, 2003).

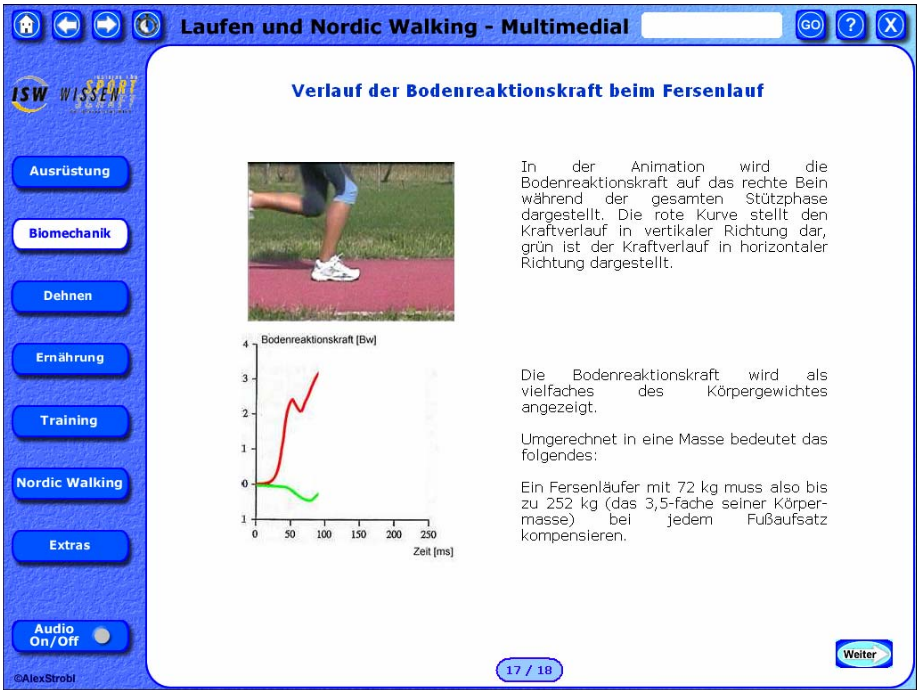


Figure 9. Combined animation and video illustration of ground reaction forces during heel running (Strobl, 2004).

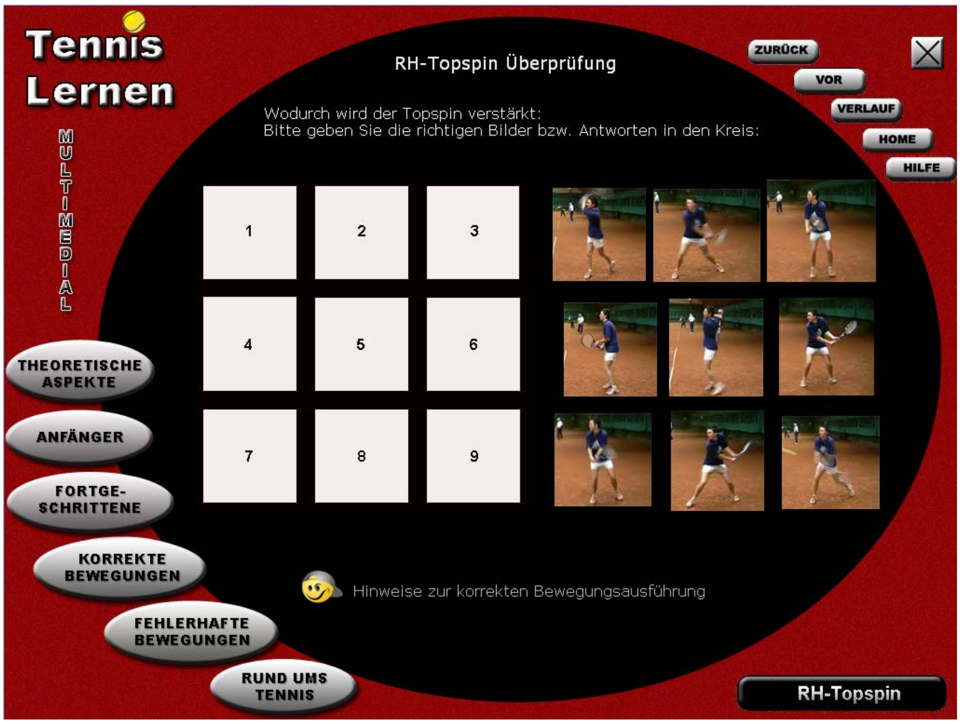


Figure 10. Puzzle to create a correct motion sequence for the backhand topspin stroke (Maruska, 2004).

It has shown that no specific courses in the relevant multimedia technologies (using authoring systems, video and sound editing, photo design and animation – in particular character animation) are required. An introductory survey, which is given in the frame of existing courses related to computer science in sport appears to be sufficient. Most students, which are interested to work in this field, are then capable to acquire the necessary knowledge rapidly on their own. Consulting hours of some student tutors, which are experienced in the relevant software packages, should, however, be provided. It often requires a short hint to help students along with software related questions. In fact, even students, who had very low experience in the programs used, were able to create considerable multimedia learning aids. However, basic information should be given to students on software project management and on aspects of usability.
The acquisition of skills and knowledge in eLearning technologies provides students with the ability to develop CBT (Computer Based Training)/WBT (Web Based Training) materials on their own. Qualifications of that kind are particularly useful in education professions (e. g. for physical education teachers) and increase career prospects.

Perspectives

Because of these developments, the amount of multimedia modules and submodules for different sports is continuously growing. A standardized, structured framework is therefore under development. eModules are organized in the form of a matrix of sports and sport scientific disciplines (Figure 11). The overall system is based on an open source based content management system (Typo3) allowing a simple integration of all information assets.

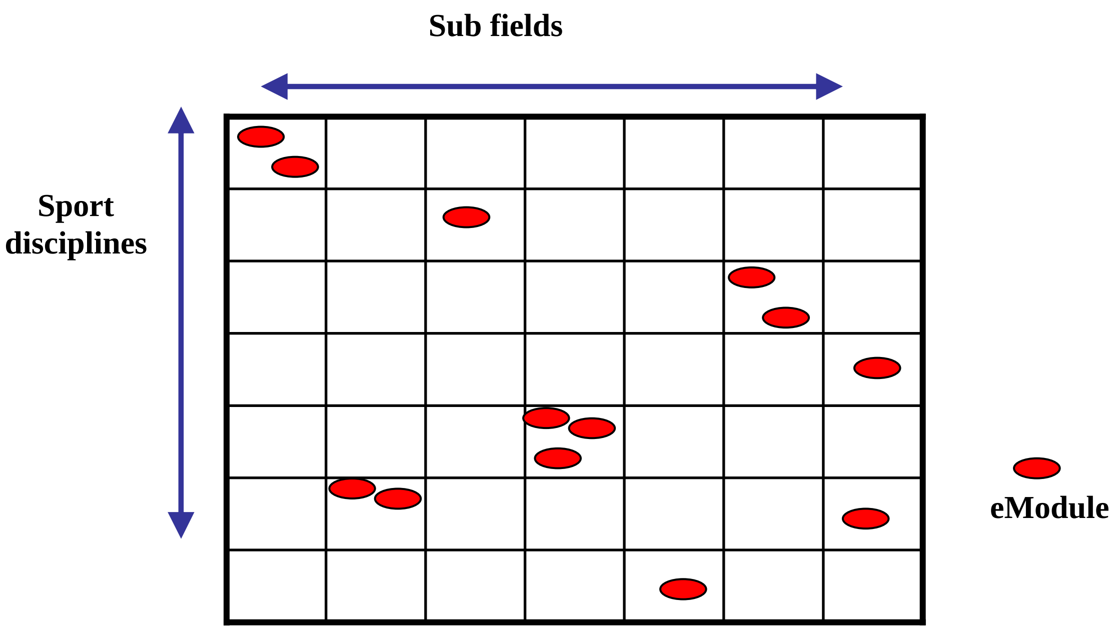


Figure 11. Content management system for eModules.

Conclusion

eLearning materials based on an interdisciplinary sports oriented concept may successfully be integrated into a blended learning setting. This concept appears to be promising, if the practical relevance of sports disciplines (principles and methods) shall be made clear to students.

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Equations for the number of matches required for stable performance profiles

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Abstract

Performance indicators in sport are often specific to individual performances rather than being typical for performers. Therefore, Hughes et al. (2004b) developed the concept of normative profiles of sports performance and a means of determining the number of matches required for performance indicators to stabilise within a tolerable percentage error of the typical mean for the performer. This technique does not address the possibility of sampling error and involves more calculation than is often necessary to determine the number of matches that are required to produce a stable performance profile. This paper develops an equation that can determine the number of matches required for the mean of a performance indicator to stabilise. Where the performance indicator is normally distributed and the coefficient of variation is 5% or less, the equation determines a number of matches required for stability with 95% confidence. The equation was tested and validated during a computerised simulation exercise that generated multiple samples of synthetic data.

Introduction

When undertaking research investigations in sport and exercise science, many believe that studies should use a sufficient sample size justified by the use of power calculations (Medicine and Science in Sport and Exercise, 2005). In scientific research, where the result of a test is not statistically significant, it is either because there is no real effect or because the research study was designed in a way that makes the detection of a real effect improbable. Power analysis allows these two alternative causes of a non-significant result to be distinguished. They are often used in trial studies to prospectively determine the sample size required to allow a real effect to be reflected by a statistically significant result when testing for that effect. The use of a representative sample is particularly important in performance analysis of sport where individual match effects render data atypical for the subjects used. Hughes *et al*. (2004b) have proposed a method for determining how much data is required for a mean to stabilise within a chosen tolerable percentage error (limits of error). However, the technique only uses the available sample of matches for the subject. Therefore, as sampling error may exist, there is a need to specify confidence limits for the number of matches required for the mean of a performance indicator to stabilise, determined using this technique. This paper refers to three different means. The *true mean* is the unknown true mean of a performance indicator for all performances. The *sample mean* is the mean of a performance indicator derived from the known available sample of values. The *cumulative mean* is the mean of a performance indicator that evolves as each value within the known sample is included.

A further criticism of the method proposed by Hughes *et al*. (2004b) is that it calculates the percentage error as each value is added in order to identify the number of values (matches) required for the cumulative mean to stabilise within the tolerable limits of error. Central Limit Theory provides a means of addressing sampling error by specifying confidence limits for the true mean of a normally distributed variable for which a sample exists and hence a simple equation can be determined for the number of matches required using the mean and standard deviation of the sample of values. The purpose of the current paper is to use central limit theory to produce an equation to calculate the number of matches (that there can be 95% confidence in) required for the mean of a performance indicator to stabilise to within the stated limits of error. This equation will only apply to normally distributed performance indicators as Central Limit Theory only applies to normally distributed variables. The paper will also explain how simulation has been used to test that the mean will actually stabilise, to within the stated limits of error, on 95% of occasions when using the number of matches computed by the equation.

Some examples of normally distributed performance indicators

Many variables in performance analysis are nominal with the frequencies of events being measured on a discrete rather than a continuous scale. Even where such performance indicators are standardised by dividing by observation time, their distributions are often skewed to the extent that non-parametric techniques are required to analyse them (Hughes *et al*., 2004a). However, there are variables such as timings and distances that are measured on a continuous scale that may also be normally distributed. Other frequency variables may be normal enough to permit the use of parametric statistics. This can be ascertained using a Kolmogorov-Smirnov test where there are 50 or more values or a Shapiro-Wilk test if there are less than 50 values. As an example, consider the performances of Venus Williams in the 26 Grand Slam singles matches she played in 2002; she reached the final of the ladies' singles in 3 of the 4 Grand Slam tennis tournaments and the quarter finals of the fourth.

Table 1. Performance indicators for Venus Williams in 26 Grand Slam singles matches played at Grand Slam tennis tournaments in 2002.

Performance Indicator	Mean±SD	CV	*p* (Shapiro-Wilk Test)
Mean first service speed (km/hour)	164.6±7.7	4.7	0.426
Mean second service speed (km/hour)	129.7±4.6	3.6	0.721
%First serves played in	56.8±7.4	13.0	0.492
%Points won when 1st serve is in	75.9±11.8	15.5	0.151
%Points won when 2nd serve is in	49.3±12.8	26.0	0.252
%Points where aces are served	6.5±4.0	61.3	0.596
%Points where double faults are served	7.2±3.8	52.7	0.408
Break points earned per set	4.0±1.4	34.5	0.068
%Break points converted	57.5±19.0	33.1	0.812
%Points where net was approached	13.8±6.7	48.4	0.003*
%Net points won	74.8±13.2	17.6	0.426
%Points where winners were played	21.0±7.9	37.8	0.994

CV = Coefficient of Variation.
* Not normally distributed

Table 1 shows that all but one of the performance indicators derived from statistics reported on the official Grand Slam tournament internet sites (Australian Open, 2002; French Open, 2002, Wimbledon, 2002; US Open, 2002) were normally distributed ($p > 0.05$). This justifies the development of the equation proposed in the current paper, but it is recommend that it is only used for performance indicators that have satisfied a Kolmogorov-Smirnov test if there are 50 or more values or a Shapiro-Wilk test if there are less than 50 values.

The equation for the number of matches required for the mean to stabilise

Let μ and σ be the true mean and standard deviation of a normally distributed performance indicator x for a given athlete. Usually there will only be a sample of performances and so μ and σ will be unknown. Instead it is necessary to use $\bar{x}$ and s which are the sample mean and standard deviation of x for the given athlete. There will be a sampling error between the true mean and the sample mean. The sample mean is normally distributed with a mean of μ and a standard deviation of $\sigma / \sqrt{n}$ where n is the sample size (number of matches) used. Therefore, 95% of sample means (where a sample size of n is used) will be found in the range $\mu \pm 1.96\sigma / \sqrt{n}$. This is because 95% of normally distributed values are within 1.96 standard deviations of the mean. However, in most scientific studies the true mean and standard deviation remain unknown. For this reason, $\bar{x}$ and s are used as estimates of μ and σ when determining confidence intervals. There could be occasions where a confidence level (p%) other than 95% is desired. Equation (1) determines the p% confidence interval where $\alpha = 1 - p/100$. The term $z_{\alpha/2}$ is the number of standard deviations either side of the mean that p% of values will fall within. In the case of a 95% confidence interval, $z_{\alpha/2}$ is 1.96.

$$p\%\ \text{Confidence Interval} = [\bar{x} - z_{\alpha/2}\, s / \sqrt{n},\ \bar{x} + z_{\alpha/2}\, s / \sqrt{n}] \quad (1)$$

In Hughes *et al.*'s (2004b) performance profiling technique, the difference between two means is determined; there is a sample mean for all of the performances being analysed and the cumulative mean as each of these performances is included. The percentage error between the cumulative mean and the sample mean is determined as each match is added. The number of matches required for the cumulative mean to fall within pre-defined limits of error of the sample mean (usually 10%, 5% or 1%) is determined. Let L be the set limits of error. The purpose of this paper is to develop an equation for the number of matches (n) required for the cumulative mean to be within L% of the sample mean with 95% confidence (where $\alpha = 0.05$ and so $z_{\alpha/2} = 1.96$). If the performance indicator is normally distributed, then after n matches one can be 95% confident that the cumulative mean will be within $z_{\alpha/2}\, s/\sqrt{n}$ of $\bar{x}$. This gives a percentage error, L, from the sample mean than can be determined by equation (2).

$$L = 100 \times \frac{1.96 s / \sqrt{n}}{\bar{x}} \quad (2)$$

Given that the coefficient of variation, CV, is the standard deviation expressed as a percentage of the mean (i.e. $100\ s / \bar{x}$) and changing the subject of equation (2) to n, gives equation (3). This gives the number of matches required to be 95% confident that the mean for any normally distributed performance indicator will fall within the chosen limits of error of the true mean.

$$n = \left(\frac{z_{\alpha/2}}{L} CV \right)^2 \tag{3}$$

For the remainder of this paper, a 95% confidence based equation ($z_{\alpha/2}$ = 1.96) will be used. Considering the data summarised in Table 1, Table 2 shows the number of matches required for the data (cumulative mean) to stabilise within 10% and 5% of the sample mean using the method of Hughes *et al.* (2004b) when the data is presented in chronological order. Table 2 also shows the result of applying equation (3) to determine values for the number of matches, with 95% confidence, required for the cumulative mean to stabilise to within 10% and 5% of the true mean. The percentage of points where Venus Williams approached the net was not normally distributed and, therefore, equation (3) could not be applied to this performance indicator.

Table 2. Number of matches required for performance indicators to stabilise within 10% and 5% of the mean for Venus Williams according to the technique of Hughes *et al*. (2004b) and the technique proposed in the current paper.

Performance Indicator	Hughes *et al.* (2004)		Equation (3)	
Limits of Error	10%	5%	10%	5%
Mean first service speed (km/hour)	1	2	1	4
Mean second service speed (km/hour)	1	1	1	2
%First serves played in	7	15	7	26
%Points won when 1st serve is in	1	6	9	37
%Points won when 2nd serve is in	8	16	27	105
%Points where aces are served	17	18	145	578
%Points where double faults are served	15	25	107	427
Break points earned per set	11	12	46	183
%Break points converted	7	18	43	169
%Points where net was approached	9	19	N/A	N/A
%Net points won	1	17	12	48
%Points where winners were played	14	19	55	220

Simulation to test the equation

A MatLab 7.0.1. (MathWorks Inc, Natick, MA, USA) program was written to generate synthetic data to test the equation (3) for the 11 performance indicators found to be normally distributed. The simulation program generated 1000 samples of 1000 sets of 11 performance indicators that were normally distributed with the means and standard deviations shown in Table 1. The means and standard deviations shown in Table 1 were assumed as the true mean and standard deviation by the simulator with the generated samples simulating sampling error. The simulation program avoided generating values outside those possible for the performance indicators; for example percentages had to be between 0 and 100. The simulation program is described by the following pseudocode.

```
Algorithm to test 95% confidence in n computed using equation (3)

1: Initialisation

     1.1 : Initialise assumed population mean's, standard
           deviations and expected n for 10% and 5% limits of
           agreement for the performance indicators.

     1.2 : Initialise counts of cases where mean stabilised within
           expected value for n.

2 : Main Simulation Loop (1000 samples of 1000 values)
FOR each of the 1000 samples

     2.1 : Determine normally distributed random values for sample
           (1000 values for each performance indicator)

     2.2 : Determine if mean for each performance indicator
           stabilised as expected within each sample

END-FOR

3 : Determine percentage of samples where each performance
    indicator stabilised as expected
```

Table 3 shows the percentage of samples that stabilised within 10% and 5% of the assumed true mean within the number of matches computed using the equation (3). The proportion was only greater than 95% for the two performance indicators with the lowest coefficient of variations when using 10% limits of error and only the performance indicator with the lowest coefficient of variation when using 5% limits of error. The percentage of aces and double faults played had the lowest proportion of samples where the values stabilised to within 10% or 5% of the assumed true mean within the number of matches the equation predicted. These two variables were found to be normally distributed according to the Shapiro-Wilk test as well as z_{Skew} and z_{Kurt} (both being within -1.96 and +1.96). However, these two performance indicators also had the highest coefficient of variations.

Table 3. Percentage of samples where mean stabilised within chosen limits of error within the number of matches predicted by equation (3).

Performance Indicator	10%	5%
Mean first service speed (km.hour^{-1})	97.1	96.0
Mean second service speed (km.hour^{-1})	99.4	94.7
%First serves played in	94.1	92.4
%Points won when 1st serve is in	94.5	90.5
%Points won when 2nd serve is in	93.5	91.0
%Points where aces are served	49.2	5.0
%Points where double faults are served	82.9	49.9
Break points earned per set	90.0	89.6
%Break points converted	93.3	89.2
%Net points won	92.8	89.3
%Points where winners were played	90.5	89.4

The simulator was altered to undertake a similar exercise using 8 arbitrary variables each with an assumed true mean of 50.0 but with the various standard deviations shown in Table 4. Considering Tables 3 and 4 together suggests that equation (3) provides a number of matches for stabilisation that one can be 95% confidence in where the performance indicator (a) is deemed to be normally distributed and (b) has a coefficient of variation of less than or equal to 5%. Where the coefficient of variation is between 5% and 30%, there can only be 90% confidence that the mean will stabilise in the number of matches as predicted by equation (3).

Table 4. Percentage of samples where mean of arbitrary variables stabilised within chosen limits of error within the number of matches predicted by equation (3).

Mean	SD	CV	10% Limits of Error	5% Limits of Error
50	0.5	1.0	100.0	100.0
50	1.25	2.5	100.0	96.2
50	2.5	5.0	95.4	94.8
50	5.0	10.0	93.8	92.6
50	7.5	15.0	93.9	92.6
50	10.0	20.0	92.4	90.8
50	12.5	25.0	91.7	91.8
50	15.0	30.0	93.2	91.2

Discussion

The performance profiling technique proposed by Hughes *et al.* (2004b) uses a sample of matches to determine how many matches are required for the mean of a performance indicator to fall within a tolerable percentage error of the sample mean. If a sample of 40 matches is used, for example, the percentage error between the cumulative mean and the sample mean will be 0% after 40 matches. However, the true mean for the performance indicator may not be equivalent to this sample mean as sampling error may exist. The equation developed herein is based on Central Limit Theory and thus recognises that there may be a sampling error. This allows for the situation where the number of matches required for stabilisation may actually be greater than the sample size. This was demonstrated by the performance indicators used from Venus Williams' data where there were 26 matches in the sample, but the equation was able to predict numbers of matches greater than 26 for some performance indicators to stabilise within 10% and 5% of the player's assumed true mean.

This equation is intended for use by those who wish to determine the number of performances they need to analyse to achieve a stable performance profile for a given athlete or team. This requires the user to set limits of error such as 10% or 5%. The validity of using a particular percentage error should be considered. An alternative approach is to relate the variability of an individual's performances to the normal spread of performances by a relevant population of players (O'Donoghue, 2005).

The equation has a restricted scope of being applied to performance indicators deemed to be normal by an appropriate test of normality and with a coefficient of variation of 30% or less. The failure of the equation to work with performance indicators with larger coefficients of variations is explained by considering the normal probability distribution. In a standard normal probability distribution, almost all of the data (99.7% of the sample) will have values within 3 standard deviations of the mean. Therefore, a standard deviation of greater than

33.3% would imply that either (a) there were more than 0.3% of the sample with values of less than 0 or greater than twice the mean or (b) the performance indicator is positively skewed. When considering distances, timings and frequencies of events in performance analysis, negative values usually don't apply. Therefore, although many performance indicators with coefficients of variation of over 30% may satisfy a standard test of normality, they are not normally distributed.

This paper has shown the value of using synthetic data to test the equation to predict the number of matches required for the mean to stabilise within given limits of error. This allowed the equation to be tested using 1000 samples of 1000 values for 11 performance indicators; this would have been extremely difficult if the study used authentic data gathered using match analysis systems. The simulator generated normally distributed synthetic data because the equation was based on central limit theory. However, other simulators developed in MatLab 7.0.1 could generate synthetic data following other distributions such as binomial distributions. There are many other applications that can be addressed in future simulation studies, for example, assessing the impact of limited reliability on the conclusions drawn from different types of performance analysis investigation. This would involve generating synthetic data that is assumed to be correct and then adding the random error discovered during reliability investigations. Similarly, the impact of using individual (and hence unrepresentative) match data on the conclusions drawn from different types of performance analysis investigation could be evaluated. Such a simulator would generate synthetic typical mean performance data and then apply the match to match variability in performance that has been established by performance profiling studies (Hughes *et al*., 2001; Hughes *et al*., 2004b). Previous investigations using multiple match data for the subjects under investigation have revealed that there is considerable within player variability for sports performance indicators (Devlin *et al*., 2004; Wells *et al*., 2004). O'Donoghue (2004) found that there was greater match to match variability in work rate for some soccer players than there was between different soccer players. Investigating the effects of limited reliability and match to match variability in data requires multiple match data for many players. If a preliminary investigation establishes within and between player distributions for performance indicators, then simulation studies may be beneficial.

Conclusions

The equation presented here is to determine the number of matches required for a performance indicator to stabilise to within tolerable limits of error of the mean. There is 95% confidence in the number of matches predicted by this equation where the performance indicator is normally distributed and has a coefficient of variation of 5% or less. Further work is required to produce similar equations for performance indicators that follow other distributions such as the binomial distribution. Further work is also required to use simulation techniques to explore the benefits of using performance profiles.

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Novel Visualization of Notational Analysis Data: The Use of Filters, 3D Graphics and Colours in Visual Identification of Playing Patterns

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Abstract

Inspired by the old adage, "a picture is worth more than a thousand words", this paper describes a novel approach to the visualization of complex cricket data. The objective is to present results to its target audience in a friendly and easily understandable manner.

In cricket, the ability to take accurate and quick decision whilst the game is being played exerts a positive influence on the result of the match. This paper describes the use of 3-D visualization of data for decision support at International level of the sport. Our results demonstrate the importance of advancing the visualization of data and the need for pattern identification tools in order to gain a competitive advantage in cricket. Modern examples are presented of the current preferred method for displaying complex notational analysis data from elite level cricket.

NOTATIONAL ANALYSIS, DATA VISUALIZATION, CRICKET ANALYSIS

Introduction

Match strategy has always been an important component of sport, particularly in the game of cricket. Tactical decisions range from choice of bowlers when facing specific batsmen and, with prior knowledge of their stroke preferences, selecting the optimum fielding positions, to the extremes such as time of the day, weather conditions, age of ball and their influence on the game. Coaches and analysts have forever been drawing complex tables of endless performance statistics, wrestling with their minds' inability to comprehend the richness of diverse and apparently unrelated information. Cricket data is in some ways similar to stock market data; patterns do exist but they are just not apparent during a superficial analysis. To make matters worse, coaches and players are very seldom mathematically minded, and therefore, their ability to digest a massive amount of tabular data is frequently limited. Presentation of data is extremely important, as the whole system is judged on its output (Hughes and Franks, 1997, p.87).

The objective of this study was to determine the ability of subjects to comprehend a vast amount of data when presented in three different formats. Data for this experiment was sourced from our notational analysis collection of past cricket matches, captured by a national team analyst. A positional data sample was then selected (point where the ball passes the cricket stumps) and presented in two forms: firstly, as an ordinary XY (scatter) graph, and secondly, within a three-dimensional model of the playing field. The two reports were presented to a number of key decision makers within the professional game of cricket, including cricket coaches and senior players. The results of the experiment are presented in this short communication.

Overview of the Game

For the sake of simplicity, we will consider only so-called “limited overs” cricket under ODI (One Day International) rules. The match consists of two parts termed “innings” (1st and 2nd). During the first inning, one team assumes the role of “bowlers and fielders”, while the other team assumes the role of “batsmen”, (referred to as “fielding” team and the “batting” team, respectively). For the following inning, these roles are exchanged so that both teams have an opportunity in the game to field and bat. The object of the game is to collect as many runs as possible. Only the batting team can score runs. The basic unit of game play is called “delivery”. It consists of the bowler delivering the ball from a predetermined distance, primarily in an attempt to hit the stumps. Stumps are three 72cm tall wooden poles standing upright behind the batsman. The batsman on strike scores runs by hitting the ball delivered by the bowler and running back and forth between the two sets of stumps as many times as possible, before the ball is returned back to the stumps by the opposing team. Each time the batsman on strike covers the distance between the two stumps one run is counted to his score (the non-striking batsman does not score runs). There are two main exceptions to this rule: if the ball crosses the boundaries of the field without being caught by a member of the opposition team, the batsman is awarded either four or six runs automatically. Six runs are awarded if the ball crosses the boundary without touching the ground. The batting team consists of ten potential batsmen. The inning is over once 300 deliveries are played, or all the potential batsmen were dismissed, whichever happens first. There are multiple ways of dismissing a batsman. Mainly, they are either “caught” or “bowled”. A batsman is given out caught when the ball is caught by any of the fielding team before it bounces. Bowled out is when the batsman fails to stop the ball, which consequently goes on to dislodge the stumps behind him. Other means of dismissing a batsman include “leg-before-wicket” (LBW), which is the most complex forms of dismissal. LBW occurs in its simplest form when the batsman misses the ball and it hits some part of his anatomy and was adjudged by the umpire to be going on to hit the stumps (It is actually a little more complicated than this, but the full explanation is beyond the scope of this paper). If the batsman steps outside a pre-determined area and the wicket keeper removes the bails after a delivery and before the batsman can regain his ground, he is given out “stumped”. “Run out” is very similar, with the striking or non-striking batsman given out if the bails are removed after delivery before he can complete his run.

The objective of the game is to score more runs than the opposition team. In order to do this, teams make use of notational analysis data for decision support. For instance, when bowling, the data is used to attempt to minimize the number of runs the opposition can score, as well as identify the areas to pitch the ball to in order to maximize the number of wickets taken from the potential 300 deliveries. Generally, at international level, each tem will have at least one notational analyst who is responsible for identifying patterns of play and determining the strengths and weakness of all players in a squad. A key component of the data analysis is to present the results to the target audience in a user friendly and easily understood manner.

Subset Under the Review

For the purpose of this short communication, we will consider the subset of the extensive cricket data, which examines the complex relationship between runs scored and the point where the ball crosses the plane passing through the stumps.

More formally, if the coordinate system were as per Figure 2 (red X-axis, green Y-axis and blue Z-axis), the plane in question would be

$$X = 0 \tag{1}$$

Figure 1 is a schematic illustration that depicts a single delivery. The bowler bowls the ball that normally bounces once (except for the so-called "full toss" delivery, where the bounce does not take place) before reaching the batsman. It is then up to the batsman to decide whether to leave the ball, or attempt to play a shot. We consider only shots that score four or six runs, as they are independent upon the batsman's running skills. Furthermore, a score of six does not depend on the position of fielders (hence reducing the number of external factors that may influence the visualization result).

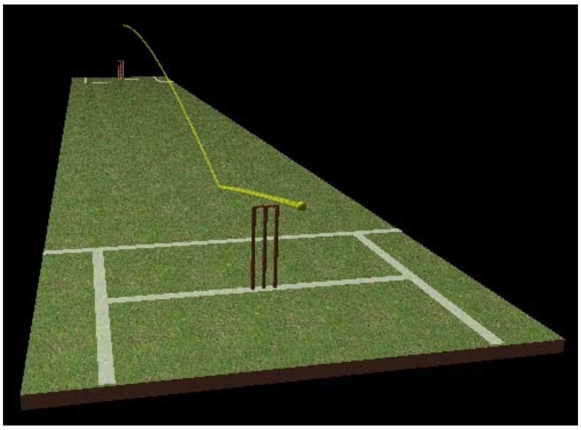

Figure 1. A sample ball trajectory

Data Collection

Data has been collected using two methods: manually, using an elite level notational analyst and by machine vision, using Hawk-Eye. Our notational analysis application, known as Crickstat, allows the analyst to assess visually the ball trajectory and mark the locations on a schematic representation of the playing field. Along with the manual logging facilities, there is an option for importing Hawk-Eye [1] data. Hawk-Eye is a system that uses several cameras and machine vision techniques in order to compute the precise trajectory of a cricket delivery. For the purpose of this paper, we used Hawk-Eye data gathered during England's tour to South Africa in February 2005.

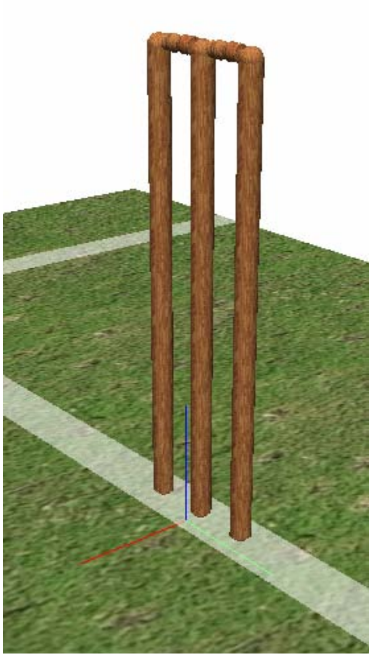

Figure 2. Coordinate system

Data Visualization

Catering for a predominantly non-scientific audience, it was our aim to present data in an intuitive manner. The data is stored in a relational database, natively in a tabular format, a small extract is shown in Figure 3.

Y	Z	Runs
0.38	0.61	1
0.43	0.52	1
0.13	0.6	1
0.39	0.21	1
0.23	0.48	1
0.4	0.47	1
0	0.69	1
0.16	0.53	1
-0.12	0.88	1
-0.17	0.72	1
0.29	0.72	1
-0.12	0.55	1
0.56	0.35	1
-0.71	0.72	1
0.41	0.19	1
0.42	0.63	1

Figure 3. Data in a tabular format

Field Y represents Y-coordinate of the point of intersection with X=0 plane, field Z represents X-coordinate of the point of intersection with X=0 plane, while Runs field represents number of runs scored for that specific delivery.

Data presented in this way is not very useful or visually insightful. The users can comprehend its meaning, but only with great difficulty and would need to maintain a high level of concentration. Simply put the data is accurate, but, conclusions cannot be drawn intuitively. The probability of spotting a meaningful pattern between the deliveries is minimal.

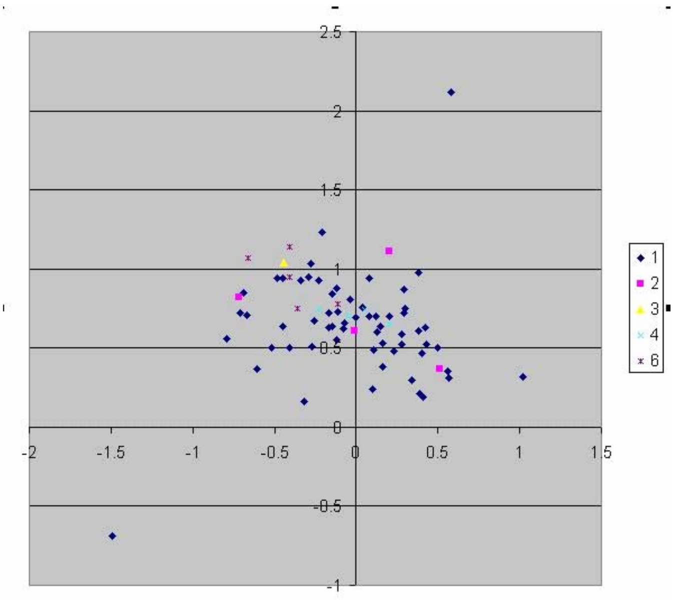

Figure 4. Data on a scatter chart

Frequently, two-dimensional data can be represented in many graphical formats, after several experiments with various standard chart types, we concluded that the most meaningful way to represent our type of data is a colour scatter chart (Figure 4). The deliveries are plotted directly on the plane and number of runs scored are colour-coded. This chart was much easier to explain to the users as patterns are easily visible. In our example, it appears that the batsman scores six runs when the ball goes to the left of the stumps at a height of approximately 1m. Therefore, in this specific example, the bowlers must refrain from bowling balls that will pass the stumps at that height and wide of off-stump.

Hughes and Franks (1997:94) discuss experiences with data presentation. They emphasize the importance of fitting the format and style to the people whom we are attempting to communicate. We went a step further and attempted to present the data in an even more discerning mode. Using the scatter graph as a starting point, we placed the same data set within a more natural-looking cricket environment in order to give a 3-Dimensional feel to the 2-Dimensional data. Dots on the scatter graph were replaced with the actual smooth-shaded balls and the results are shown in Figure 5.

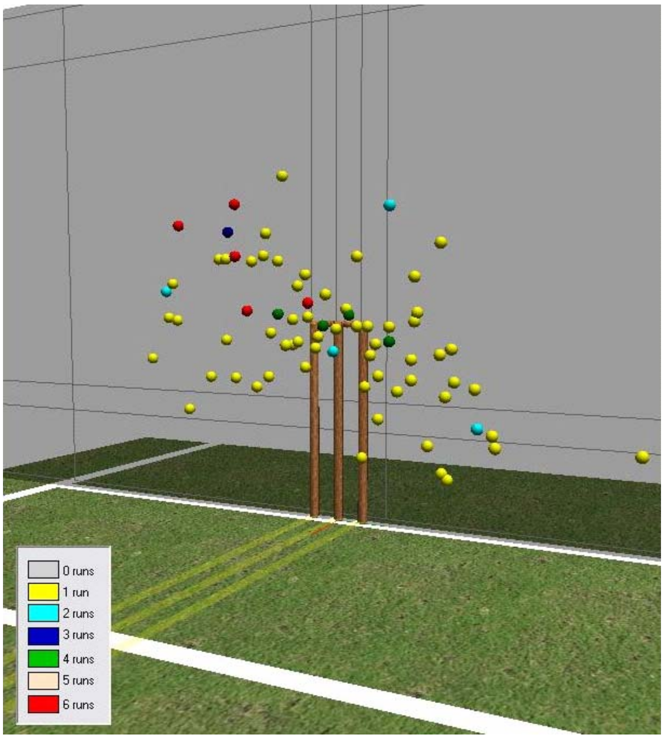

Figure 5. Data in a simulated environment

Match data (extracted from the analysis of the England tour to SA) in tabular, scatter graph and 3-D simulated environment was shown to every member of the South African squad during the New Zealand tour to South Africa in 2005 (14 players and 2 coaches). Without exception every member of the squad found the 3-D simulated environment needed less explanation than any alternative representations. Every one of the subjects identified what it represented at first glance. The visual pattern finding clearly verifies for instance our previous remark; one can immediately "see" the deliveries resulting in scoring six runs on this chart (red balls).

Data Filtering

In order to reduce the number of variables even further, data may be interactively filtered via one or more filters, as depicted in Figure 6. The user may, for example, see all the balls bowled by a particular bowler to a particular batsman, where the batsman scored three or more runs. Since the data filtering is near-instantaneous, the user is able keep several variables constant, while moving back and forth rapidly through a variable of interest and visually comparing the change in displayed data (e.g. keeping the batman constant and rapidly change the bowlers in order to identify visually interesting patterns of batsmen's response to different bowlers). Such techniques are critical during a match for decision makers in teams in order to isolate and optimize match strategies and tactics.

Conclusion and Future Work

We will continue advancing our work on the visualization of match data using the following two approaches. Firstly, we plan to involve multiple variables, such as the correlation between pitch area, stump pass point and the wagon wheel position. Secondly, by doing so, we should not forget to work on the intuitiveness of the interface and the visualization itself. The key objective is to present complex data in an easily understood manner that will have a positive effect on the outcomes of games.

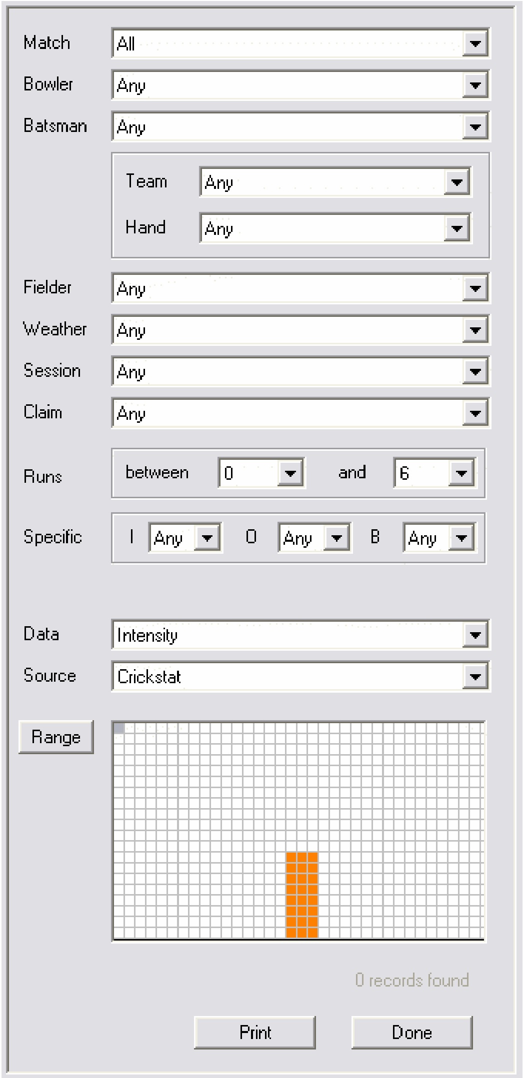

Figure 6. Data filters

Acknowledgments

We would like to thank Hawk-Eye Innovations for making the trajectory data available; it made a significant contribution to the accuracy of our visualization work.

References

Hawk-Eye Innovations Ltd., http://www.hawkeyeinnovations.co.uk/

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