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Editorial

Arnold Baca

Department of Biomechanics, Kinesiology and Applied Computer Science,

ISW, University of Vienna

Dear readers:

Welcome to the first issue of the **International Journal of Computer Science in Sport** (**IJCSS**) in 2004.

One year has passed since the formal foundation of the **International Association of Computer Science in Sport** (**IACSS**) in Barcelona. In March, 2004, IACSS has become an institutional member of **ICSSPE**, the **International Council of Sport Science and Physical Education**. In the course of this new cooperation a symposium on "Computer Science in Sport" has been organized as part of the 11th Pre-Olympic Congress (August 6-11, 2004) in Thessaloniki, Greece.

National and international conferences as well as sessions and symposia on "Computer Science in Sport" within the scope of conferences and congresses (e.g. 1st International Working Conference IT and Sport & 5th Conference dvs-Section Computer Science in Sport – Cologne, September 15-17, 2004; 7th Conference on Mathematics and Computers in Sport – Massey University, Palmerston North, New Zealand, August 30 - September 1, 2004) have been organized in 2004. These events are the basis and are impressive signs for the fruitful development of the field of **Computes Science in Sport**.

Four original papers and one extended essay have been included within this issue.

In the paper by **Peter O'Donoghue** and **Jason Williams** the accuracy of human and computer-based methods of predicting the 2003 Rugby Union World Cup are compared. From the results it can be concluded that computer-based methods are more successful at predicting the outcomes of international rugby union matches than the average human, but are not as successful as human experts.

Chris Chisamore, **Larry Katz**, **Dave Paskevich** and **Gail Kopp** review the areas of sport efficacy and sport technology as they relate to athlete performance. Their paper deals with the rather new and interesting demand of providing the athlete with more individual information in order to improve training and performance. It gives a very good overview on media-support in sports. The tools presented can be used by elite level athletes to help them mentally prepare for competition and peak athletic performance.

Neville de Mestre discusses the mathematics and physics of body-surfing techniques and of the different types of waves involved in this sport discipline.

A mathematical model is presented by **Mike D. Quinn,** which is used to simulate the effect of wind conditions on men's and women's 200-m times. Selected questions are investigated and discussed.

In the extended essay by **Jürgen Perl** and **Kathrin Weber** a Neural Network approach to learning patterns in sport is presented. The question of continuing learning of Neural Networks is addressed.

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

Good reading!

Arnold Baca, Editor in Chief
University of Vienna, arnold.baca@iacss.org

An Evaluation of Human and Computer-Based Predictions of the 2003 Rugby Union World Cup

Peter O'Donoghue[1] *and Jason Williams*[2]

[1]*School of Sport, Physical Education and Recreation, University of Wales Institute Cardiff, Cyncoed Campus, CF23 6XD.*

[2]*International Rugby Board, Game Analysis Centre, University of Wales Institute Cardiff, Cyncoed Campus, CF23 6XD.*

Abstract

The purpose of the current investigation was to compare the accuracy of human and computer-based methods of predicting the 2003 Rugby Union World Cup. The computer-based methods were multiple linear regression, binary logistic regression, artificial neural networks and a simulation package. The computer-based methods used data from the previous 4 Rugby Union World Cups to develop predictive models of international rugby union results based on team strength, distance travelled to the tournament and recovery days between matches. The computer-based methods correctly predicted between 39 and 44.5 of the 48 matches which was more accurate than the 40.66 averaged by 42 individual humans. However, there was a far greater range of accuracies for the human predictors with the most successful human correctly predicting the outcomes of 46 of the 48 matches. Furthermore, an expert focus group successfully predicted 43 of the 48 matches which was better than the average computer-based method. The most successful of the computer-based methods was a simultion model. The accuracy of the artificial neural network predictions increased with the number of nodes within the middle layer. The study provided evidence that computer-based methods are more successful at predicting the outcomes of international rugby union matches than the average human, but are not as successful as human experts.

KEY WORDS: PERFOMANCE MODELLING, PERFORMANCE PREDICTION

Introduction

The ability to forecast is very important to decision making in many diverse fields including medicine and business. Forecasting is based on prior knowledge and research of the effect of relevant factors on relevant dependent variables. However, in many areas, forecasting remains difficult to do accurately. This is due to the complexity of the behaviour of interest as well as the large number of relevant factors. Many factors are often difficult to define and measurements used may be of limited reliability and validity. In some areas accurate predictive models have been used successfully while in others more subjective analysis by human experts is preferred. Team sports are an example of dynamic and complex situations with problems relating to time, space, information and organisation (Grehaigne *et al*., 1997).

The predictability of a game depends on the ease of scoring (Stefani, 1998). Therefore, a sport like soccer will be harder to predict than rugby union or basketball. Similarly, if we consider probabilistic models of tennis (Schutz, 1970), there is a greater chance of the inferior player within a match winning if the match is the best of 3 sets than if the match is the best of 5 sets. Soccer is a particularly challenging example of a situation where forecasting is complex (Buchner *et al*., 1997). In a study of quantitative and qualitative methods of predicting the 2002 FIFA World Cup for soccer (O'Donoghue *et al*., 2003), no method successfully predicted more than 4 of the 8 quarter finalists and no method predicted more than 1 of the 4 semi finalists.

Rugby union is a higher scoring sport than soccer, which makes upsets less likely than in soccer. Other reasons for international rugby union matches being more predictable than international soccer matches are the lower strength in depth in international rugby union as well as the greater number of set plays, which lead to more structure in the game so as planning and strategy can be more effective. However, betting agencies are still prepared to take bets on the outcomes of international rugby union matches illustrating that the outcomes of matches are not certain. Computer-based methods of predicting match outcomes have been evaluated against the predictions of humans using international soccer matches (O'Donoghue *et al*., 2003). However, there is no such evaluation using international rugby union matches. The importance of undertaking such an evaluation exercise is to test the various methods of prediction using a sport with a different degree of uncertainty to soccer. The purpose of the current investigation was to compare alternative methods of predicting the 2003 Rugby World Cup. These methods ranged from the highly qualitative to computer-based methods that used exclusively quantitative data.

The Prediction Task and Evaluation Method

The prediction task was composed of two parts; the prediction of the 40 pool matches of the 2003 Rugby World Cup and the prediction of the tournament's 8 knock out stage matches. All match predictions had to be submitted before the first match of the tournament was played. The second part of the prediction task was particularly challenging as it was not certain as to which teams would be competing in the knockout stages. Prediction errors made for the pool matches would propagate into the predictions of the knockout matches. For each pool match, each prediction had to predict the outcome (win, draw, lose) with respect to superior team within the match. The superior team was the higher ranked team according to the Zurich World Rankings. The predictions were given 1 mark for each pool match where the outcome was correctly predicted. Where the prediction was a draw but the actual match was won by one of the teams, 0.5 marks were awarded. Similarly, 0.5 marks were awarded where a win was predicted for one of the teams but the actual match resulted in a draw. Those making predictions were advised that in the 137 matches of the 4 previous world cups, there had only been 1 draw. The predictors were also made aware of the timetable of matches and the world rankings of the teams.

The second part of the prediction task required the predictors to identify the teams involved in each quarter-final, semi-final, 3rd place play-off and the final. They also had to predict the winners of the 3rd place play off and the final. The predictions were awarded 1 mark for each of the 8 knockout stage matches for which winning team was successfully forecasted. This gave a maximum of 48 marks for each prediction. Those responsible for each prediction completed a form to submit predictions of the pool matches and knock out stages. The predictions were entered into a Microsoft Excel spreadsheet that determined the pool winners and runners up based on the predicted pool matches. This allowed the consistency of the pool match predictions and knockout predictions to be checked. Eight individual predictors had inconsistent pool results and quarter-final line ups. These individuals were asked to either change the pool match predictions or the line up of quarter-finalists to ensure that the predictions were consistent.

Human-based Prediction Methods

Individual Human Predictions

	Quarter Finals	Semi Finals	3rd Place Play Off	Final
Winner Pool A	Australia (37) Ireland (4) Argentina (1)			
Runner Up Pool B	Scotland (26) Fiji (14) Japan (1) France (1)	Australia (37) Other (5)		
Winner Pool D	New Zealand (41) Tonga (1)	New Zealand (39) Other (3)		
Runner Up Pool C	South Africa (37) England (4) Samoa (1)		Australia (27) New Zealand (11) Other (4)	New Zealand (28) Australia (13) Other (1)
Winner Pool B	France (41) Fiji (1)		France (25) Ireland (13) Other (4)	England (36) France (2) Other (4)
Runner Up Pool A	Ireland (32) Argentina (6) Australia (4)	France (27) Ireland (15)		
Winner Pool C	England (38) South Africa (4)	England (38) South Africa (4)	3rd Place	World Champions
Runner Up Pool D	Wales (32) Canada (4) Italy (3) Tonga (3)		Australia (23) New Zealand (11) France (4) Other (4)	New Zealand (20) England (13) Australia (8) S Africa (1)

Figure 1. Summary of the 42 individual human predictions for the knock out stages. The figures in parenthesis are the number of predictions forecasting the named team to reach the particular stage.

The individual human predictors were initially recruited from staff within an academic sport, and physical education department of a university. Further human subjects were recruited by the initial set of subjects. This snowball sampling approach provided 42 responses overall. These predictions used varied sources of complex information and knowledge to forecast the results of matches and the eventual outcome of the tournament. The predictions were based on rich subjective information derived from media sources, internet reports as well as perceptions relating to relevant factors such as home advantage and the importance of rugby union within the different nations. These predictions had the scope to use anecdotal evidence as well as apply different levels of relevance and importance to various factors. A common sub-task that emerged during the prediction process was the prediction of upsets. Given that there were very few drawn matches in international rugby union, the prediction task soon became abstracted to a task of predicting the number of upsets and which matches were most likely to be upsets. Those individual human predictors who followed this approach spent much of their analysis considering acts of “giant killing” and the ingredients of such feats. Figure 1 summarises the predictions made by the 42 individuals for the knock out stages.

Expert Focus Group

The expert focus group was composed of four rugby union experts. One of these was a professional rugby player, one a former international rugby referee, one a video analyst for a professional rugby team and one a sports software developer. All four were also professional rugby analysts. The knowledge used was of a similar type and complexity to that used by the individual human predictors, except that the focus group used shared knowledge with the need to negotiate a joint prediction. Besides being composed of more than one person, the other difference between the expert focus group and the individual human predictors was that the knowledge and experience of the expert focus group was much greater than the typical individual predictor although there were four qualified rugby union coaches among the individual predictors. The focus group agreed on the prediction shown in Figure 2.

	Quarter Finals	Semi Finals	3rd Place Play Off	Final
Winner D	Australia			
Runner Up C	Fiji	Australia		
Winner A	New Zealand	New Zealand		
Runner Up B	South Africa		Australia	New Zealand
Winner B	France		France	England
Runner Up A	Ireland	France		
Winner C	England	England	3rd Place	World Champions
Runner Up D	Wales		Australia	England

Figure 2. Prediction for the knockout stage made by the Expert Focus Group.

Data used by Computerised Methods

There are many factors that influence performance in sport; these factors have varying degrees of complexity and validity. The computer-based predictions modelled the relationship between the result of a match and three relevant factors in the 137 matches of the previous 4 Rugby World Cups (1987, 1991, 1995 and 1999). The three factors used were team strength, distance travelled to the tournament and recovery days between matches. Strength of teams (and individuals in individual sports) have been estimated by rankings is boxing, soccer, tennis, golf and chess (Stefani, 1998). The acceptance of these rankings is an indication of their validity. A comprehensive review of home advantage in sport (Courneya and Carron, 1992) has shown that home advantage undoubtedly effects performance in sports competitions. There are various explanations of this including the crowd influencing decisions in favour of the home side (Nevill *et al*., 2002). The 2003 rugby world cup commenced with 4 groups of 5 teams; therefore the round robin structure of each group would involve 5 pairs of matches with one team not playing in either match of the pair. This leads to large differences in the recovery days from previous matches between the teams contesting some group matches. For this reason, recovery advantage was included as a factor. Other factors do exist but are difficult to measure in a manner suitable for entry into the computerised systems used in the current study.

The Zurich World Rankings not only rank the teams in descending order of perceived strength but also provide ranking points for each team. The final column of Table 1 shows the world ranking points for the sides involved in the 2003 World Cup. Unlike soccer, where FIFA have provided world rankings and ranking points since 1993, there were no official world rankings for international Rugby Union during the previous 4 World Cups. It was, therefore, necessary to devise a method of synthesising world ranking points for the teams that participated in the previous 4 World Cups. This was undertaken during a peer review exercise. The teams were arranged into five groups of different perceived strengths. The first group contained Australia, New Zealand and South Africa. Each of these teams were initially awarded 1000 synthetic world ranking points with an additional 400 synthetic world ranking points being divided between them based on results of matches between the sides in matches over the two years that preceded each World Cup. The second group was the “Five Nations” (England, France, Ireland, Scotland and Wales) because the “Six Nations” did not commence until 2000. The synthetic world ranking points (RP) given to each team was determined as a function of the total number of points achieved in the Five Nations championships in the previous two seasons (PFN) prior to a World Cup. Equation (1) was agreed as it gave a range of synthetic world ranking points that was felt to represent the regional strength of the five nations in comparison to other regions.

$$RP = 640 + 30 \times PFN \qquad (1)$$

Where two teams had the same number of synthetic world ranking points and played each other within a particular World Cup, it was necessary to identify one as the stronger. This was done using the result of the last match between the two sides prior to the World Cup, adding 10 to the synthetic world ranking points for the winner and subtracting 10 from the loser’s. This had to be done when England and Wales were given 820 synthetic world ranking points for the 1987 World Cup.

The third group contained the five remaining nations who had participated in all 5 World Cups; Argentina, Canada, Italy, Japan and Romania. These teams were initially awarded 400 to 600 synthetic world ranking points based on matches between them in the two years leading up to a World Cup. These were then considered with respect to matches against other nations and some adjustments made; in one case it was decided to give Italy 650 synthetic world ranking points for 1999. The fourth group contained the four countries who had participated in 3 of the previous World Cups; Fiji, Samoa, Tonga and USA. It was decided to give these teams between 400 and 650 synthetic world ranking points based on matches between them in the two years leading up to a World Cup. Once again, these were adjusted based on matches against other nations in the two years that preceded a World Cup. Finally, synthetic world ranking points for the 5 nations that had participated in 1 or 2 previous World Cups were determined; Ivory Coast, Namibia, Spain, Uruguay and Zimbabwe. These countries were given between 200 and 250 synthetic world ranking points based on matches played in the two year period leading up to a World Cup. Table 1 shows the synthetic world ranking points that were finally agreed.

Table 1. World Ranking Points for the participants in the 2003 Rugby World Cup and synthetic World Ranking Points for the participants of previous World Cups.

Team	1987	1991	1995	1999	2003
England	810	1060	1040	1000	1298
New Zealand	1210	1240	1300	1140	1278
Australia	1190	1160	1100	1160	1108
France	1060	940	880	940	1103
South Africa			1000	1100	1006
Ireland	760	760	790	700	929
Argentina	600	610	550	610	858
Scotland	940	1000	850	890	756
Wales	830	700	820	870	699
Samoa		650	640	650	675
Canada	500	500	480	525	569
Fiji	650	590		590	561
Italy	500	550	600	650	549
Tonga	525		500	550	527
Japan	430	430	600	450	457
USA	400	440		425	445
Georgia					363
Romania	400	400	400	400	357
Namibia				250	303
Uruguay				200	295
Zimbabwe	200	200			
Ivory Coast			200		
Spain				225	

The distance travelled by a national team to a World Cup was estimated using the giant circle distance (in imperial miles) between the capital city of that nation and the capital city of the host nation. This information was obtained from an internet site that calculated the giant circle distances (Indonesia, 2003). This gave a crude but objective indication of home advantage. With some previous World Cups being played in more than one country, visiting teams had different values for this variable within the same tournament depending on where matches were being played.

The timetables of matches for each of the previous 4 World Cups were examined to determine the recovery advantage of the superior team within each match. The superior team was the team with the higher synthetic world ranking points. If both teams were playing their first match then the recovery advantage was 0. Where two teams had already played in one or more matches during the tournament the number of days recovery from the inferior team's last match was subtracted from the number of recovery days from the superior team's last match.

The results of the matches of the 1987 and 1991 World Cups were adjusted so as a try was worth 5 points instead of 4 points because the 2003 tournament that we were predicting awarded 5 points for a try. This resulted in the one drawn match in the previous World Cups becoming a win for one of the sides for the purposes of the current study. Therefore, no previous World Cup matches were considered to be draws. The points scored (based on 5 points for a try), number of tries, conversions, penalties scored and drop goals converted were all recorded for the 137 matches of the previous World Cups.

Computerised Methods

The computerised methods use similar information with some differences that are highlighted in Table 2.

Table 2. Data Variables used in different computerised methods

Method	Variables used															
	Ranks	Distances Travelled	Recovery days since last match	Rank difference	Distance difference	Recovery advantage	Rank difference (Normalised)	Distance difference (Normalised)	Recovery advantage (Normalised)	Points Difference	Points Difference (Normalised)	Tries scored	%Tries converted	Penalties scored	Drop Goals scored	Outcome (Win / Lose)
Multiple linear regression (satisfies assumptions)							X	X	X		X					
Multiple linear regression (violates assumptions)				X	X	X				X						
Binary logistic regression				X	X	X										X
Neural networks with numeric input	X	X				X										X
Neural networks with binary input	X	X	X													X
Simulation Package	X	X	X									X	X	X	X	

Multiple Linear Regression

Data from the 137 matches from the four previous World Cups were analysed in terms of the three factors. Each factor as well as the match score was represented as a difference between the superior team and the inferior team. In other words, the point difference between the two teams was used instead of the points scored by the two individual teams. We produced two multiple linear regression models using SPSS version 11.5. One of these predictions used unadjusted difference variables to predict points difference in terms of strength difference, distance travelled difference and difference in recovery days from previous match. This regression model is shown in equation (2). A predicted points difference of between -0.5 and +0.5 counted as a draw. This model violated the assumptions of multiple linear regression.

A second regression model was produced to satisfy the assumptions of multiple linear regression relating to the distribution of residuals, the independence of predicted scores and studentised residuals as well as the independence of residuals from the chronological order of the 137 previous World Cup matches used. This was achieved by producing mapping functions that mapped each variable with a sequence of 137 values within a standard normal distribution (mean = 0, SD = 1). The normalised versions of the difference variables (synthetic world ranking points, distance travelled to the tournament and recovery days between matches) were then entered into a regression analysis in SPSS to determine a prediction model for the normalised version of the point difference. There were 21 upsets within the previous 137 World Cup data. This meant that values between the 21st and 22nd of the 137 z-scores would indicate a draw. These z-scores were -1.01 and -0.98 respectively, but none of the 40 pool matches or 8 predicted knock out matches of the 2003 Rugby World Cup were predicted to be a draw when the regression model based on normalised variables (equation (3)) was applied.

$$PtsDiff = 3.2 + 0.0598\ RankDiff + 1.778\ RecAdv – 0.000114\ DistDiff \qquad (2)$$

$$Z\text{-}PtsDiff = 0.00659 + 0.574\ Z\text{-}RankDiff + 0.0895\ Z\text{-}RecAdv – 0.0271\ Z\text{-}DistDiff \qquad (3)$$

Note that *RankDiff* is the difference between the superior and inferior teams' synthetic world ranking points, *RecAdv* is the number of extra recovery days the superior team had over the inferior team and *DistDiff* is the difference between the distance travelled to the tournament by the superior and inferior teams. Variables preceded by *Z* are normalised versions of the difference variables. It should be noted that the original multiple linear regression produced residuals that a Kolmogorov-Smirnov test showed to violate the assumption of normality ($P < 0.001$). However, the residuals produced by the multiple linear regression that used normalised difference variables were sufficiently normally distributed ($P = 0.064$) and there was no relation to predicted values ($r = -0.001$) or order of match ($r = 0.040$).

Binary Logistic Regression

The model based on binary logistic regression used the same three difference variables as the first multiple linear regression model. However, instead of trying to predict the point difference between the two sides, it predicted a match outcome (win or lose) with respect to the superior team. The use of binary logistic regression rather than discriminant function analysis was based on an assumption that there would be no drawn matches. The regression coefficients were determined using SPSS version 11.5 and placed into equation (4) which was used to predict the match outcome for the 40 pool matches of the 2003 World Cup. The results of the expected knock out matches were also determined using the same equation.

$$Outcome = e^{y} / (1 + e^{y}) \qquad (4)$$

$$y = -0.3317 + 0.00988\ RankDiff – 0.1466\ RecAdv + 0.0000643\ DistDiff \qquad (5)$$

An outcome score of more than 0.5 represented a win for the superior team while an outcome score of under 0.5 represented a win for the inferior team.

Artificial Neural Networks

The Backpropagation algorithm was used in the current investigation. This algorithm has been used with binary data entering its input layer in previous research in speech analysis

(Keating *et al*., 1995); each input node being normalised to have a value between 0.0 and 1.0. Within the current investigation, 8 different neural network structures using the Backpropagation algorithm were applied. Four of these had 14 input nodes using binary input (0 or 1) while the other four had 5 input nodes using numeric input (values ranging from 0.0 to 1.0). Each type of input node was used within 4 neural network structures with different numbers of middle layer nodes (4, 8, 16 and 32) within a single middle layer. Each neural network had an output layer of two nodes; one representing a win for the superior team and one representing a win for the inferior team. All eight neural networks were fully connected between the input layer nodes and middle layer nodes as well as between the middle layer nodes and the output layer nodes. Each neural network was trained using the data set of 137 previous World Cup matches and then used to predict the 40 pool matches of the 2003 World Cup as well as the knock out matches predicted to take place in each case.

Each neural network using binary input data neural network had 14 input nodes. Three input nodes were used to represent the home advantage of the superior team. The first indicated whether or not the match was being played in the team's own continent, the second indicated whether the match was being played within the team's own region and the third indicated whether the match was being played in the team's own nation. A further three input nodes were used to represent the home advantage of the inferior team. The difference between the superior and inferior teams' strengths was divided by 20 and truncated. This gave a value between 0 and 63 which was represented as a 6-digit binary number which populated 6 further input nodes. The remaining 2 input nodes were used to represent recovery days. One node was used to represent whether or not the superior team had more recovery days from the previous match than the inferior team. A further input node represented similar information for the inferior team. There were only two nodes in the output layer; one representing a win for the superior team and one representing a win for the inferior team.

The 5 input nodes of the neural network using numeric data could use a range of values from 0.0 to 1.0. The first input node was used to represent the strength of the superior team which was divided by 1300 to give a value of between 0.0 and 1.0. The second input node represented the strength of the inferior team in the same way. The third input node was used to represent the distance between the capital city of the superior team and the capital city of the country where the match was played. This was divided by 12500 miles, half of the circumference of the equator, to give a value between 0.0 and 1.0. The fourth input node was used to represent the distance travelled by the inferior team in the same way. The fifth input node was used to represent the recovery advantage of the superior team. The value 8 was added to the number of additional recovery days the superior team had over the inferior team since their previous matches within the tournament. The resulting value was then divided by 16 to give a value between 0.0 and 1.0 with 0.5 representing those cases where the two teams had the same number of recovery days since their previous matches.

The Backpropagation algorithm was applied with 4 different sizes of middle layer (4, 8, 16 and 32 nodes) for the networks using binary as well as numeric input nodes. This gave a total of 8 artificial neural network models. There were 137 training matches from the previous 4 World Cups and 48 matches from the 2003 World Cup used to test the recognition ability of the neural network. Table 3 shows the number of epochs per training match required to train each neural network as well as the number of matches in the 2003 World Cup where an upset was predicted. An upset is defined as a win for the inferior team within a match.

Table 3. Summary of training and prediction data for the 8 neural network models.

Input node type	Middle layer nodes	Epochs per training match	Upsets predicted in pool matches	Upsets predicted in KO matches
Binary	4	73.69	3	1
	8	56.34	2	1
	16	40.38	1	0
	32	22.30	0	0
Numeric	4	110.83	0	0
	8	63.09	0	0
	16	36.79	0	0
	32	21.16	0	0

Simulation Package

The idea of the simulator was that it would play a virtual match, synthesizing the scoring of tries, conversions, penalties and drop goals. In order to do this, the points difference predicted in the multiple linear regression model and the match outcome used in the binary logistic regression model were insufficient. Instead, the simulator used models based on the effect of the three factors on each of the following types of scoring for both the superior and inferior teams within a match; number of tries, fraction of tries that were converted, number of penalties converted and number of drop goals converted. This gave a total of 8 separate regression equations that were determined in SPSS version 11.5 using the 137 matches from previous World Cups. Therefore, the linear regression equations were used to determine expected numbers of score types rather than the result of simulated match. The simulation package ran a simulated World Cup 2000 times simulating each match using the expected number of tries, fraction of tries converted, penalties converted and drop goals converted as weightings to be used with the random numbers generated in the simulation. The weightings were used to appropriately bias the simulator in favor of the expected match winner according to the eight regression equations. The random numbers introduced the aspect of chance and variability about the expected result that is absent from the other quantitative predictions. Figure 3 shows uses a Yourdon chart to show the simulator algorithm.

The simulator divided the match into T time slots. If a particular team was expected to score 3.6 tries within a match, the probability of scoring a try within a single time slot was 3.6 / T. Therefore, when a random number between 0.0 and 1.0 was generated by the simulator, a value of 1 – (3.6 / T) or above was required for a simulated try to be scored. Consider a team expected to score 5.2 tries and a simulator using 100 time slots. The chance of a simulated try in any time slot would be 0.052, so a random number between 0.0 and 1.0 would have to exceed 0.948 for a simulated try to be awarded to the team in any time slot. The scoring of other types of points was simulated in the same way. The simulator was run using different numbers of time slots and counting the number of wins for the inferior team within a match as well as the number of draws. With a win for the inferior team counting as an upset and a draw counting as 0.5 of an upset, the percentage of upsets predicted by the simulator is shown in Table 4 for different numbers of time slots. The figures in Table 4 were related to the total of 96000 matches played during the 2000 simulated World Cups that occur within a simulated run. In previous World Cups, there had been 21 upsets out of 137 matches (15.3%). It was therefore decided to simulate the World Cup using 30 time slots.

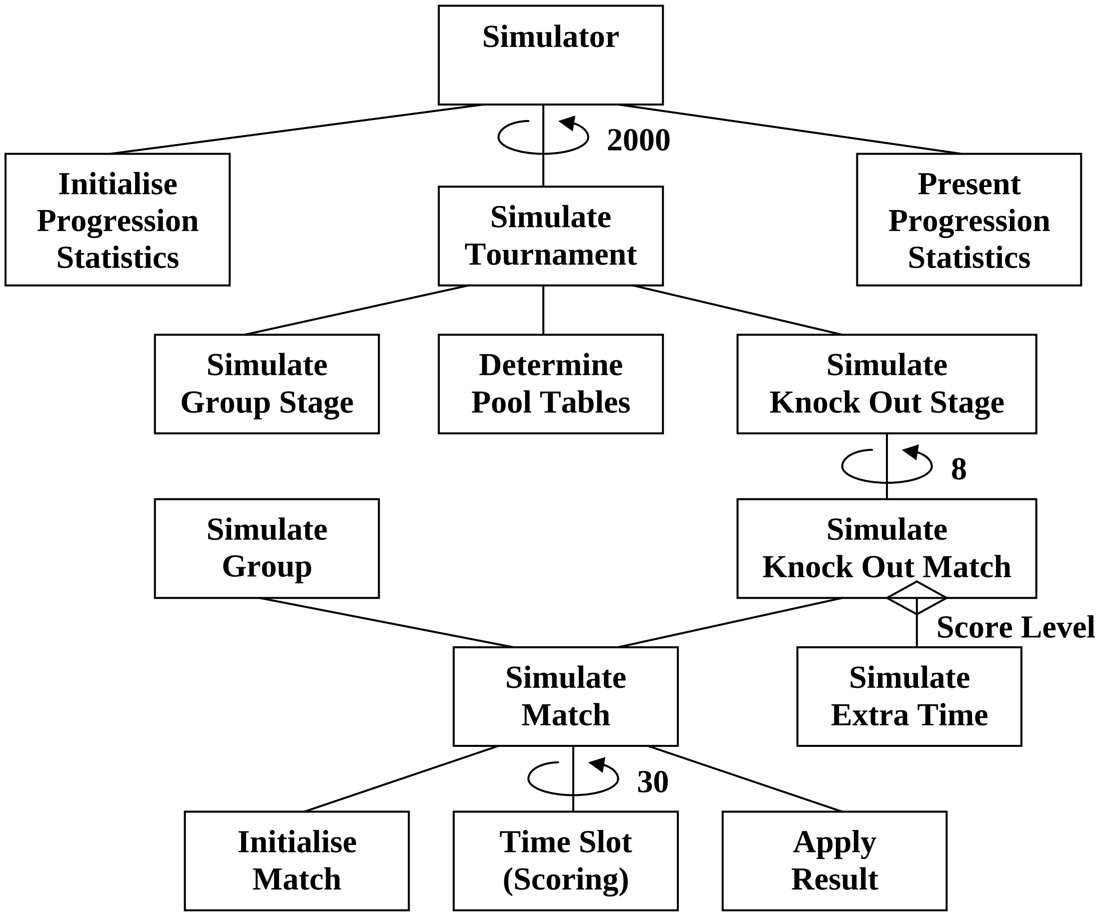

Figure 3. Simulator Algorithm.

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Table 4. Percentage of upsets predicted by the simulation package when using different numbers of time slots during a simulated match.

Time Slots	Wins for the inferior team	Draws	%Upsets
10	8256	1097	9.2
20	10309	1489	11.5

30	13884	1658	15.3
40	14659	1866	16.2
50	14334	1507	15.7
60	11441	1622	12.7
70	8775	1173	9.8
80	7719	1239	8.7

Because the simulator simulated the tournament 2000 times, there were 2000 results for each of the 40 pool matches. The system showed the percentage of wins for each team within each pool match as well as the percentage of draws. Where one match outcome type had more than a 5% greater amount of simulated occurrences than each of the other two outcome types, that outcome was selected. If the most likely outcome according to the simulator had less than a 5% greater chance of occurring than the second most likely outcome, then a draw was predicted. Within each simulated World Cup, the pool tables and hence the quarter finals line up were determined using the same system as the actual Rugby World Cup. For the purpose of the current investigation, it was necessary to produce a single prediction from the 2000 simulated World Cups. The prediction shown in Figure 4 used progression statistics generated during the 2000 simulated World Cups. The winner and runner-up of each group were predicted as the team who won the group most times and the remaining team that qualified from the group most times respectively. England was selected as tournament winners as they won the largest number of simulated World Cups (1151 out of 2000). New Zealand was selected as a finalist as they were the team in the other half of the knock out structure to reach the final most often (during 48% of simulated World Cups). The other two semi-finalists were predicted as the two teams who progressed to the semi-finals in the other two quarters of the knock out structure most often during the 2000 simulated World Cups. These were France and Australia. France finished 3rd in more simulated World Cups than Australia and so France was predicted to come 3rd.

	Quarter Finals	Semi Finals	3rd Place Play Off	Final
Winner D	Australia 66%			
Runner Up C	Scotland 72%	Australia 59%		
Winner A	New Zealand 99%	New Zealand 60%		
Runner Up B	South Africa 73%		Australia 45%	New Zealand 48%
Winner B	France 96%		France 47%	England 59%
Runner Up A	Ireland 54%	France 72%		
Winner C	England 80%	England 77%	3rd Place	World Champions
Runner Up D	Wales 70%		France 26%	England 57%

Figure 4. Prediction for the knockout stage made from the 2000 simulated World Cups with the percentage of simulated World Cups where the predicted team reached each location.

Evaluation Results

The predictions of the 12 computer-based methods were very similar with agreement about 7 of the 8 quarter finalists, 3 of the 4 semi-finalists and all predicting an England versus New Zealand final. The remainder of this evaluation will consider the artificial neural networks that used numeric input nodes as a single method as all four versions produced identical predictions. Therefore, we are evaluating 9 computer-based methods against the prediction performance of the expert focus group as and the 42 individual human predictions. Figure 5. Prediction for the knockout stage made using the computer-based methods.

	Quarter Finals	Semi Finals	3rd Place Play Off	Final
Winner D	Australia			
Runner Up C	Scotland	Australia		
Winner A	New Zealand	New Zealand		
Runner Up B	South Africa		Australia	New Zealand
Winner B	France		France ^	England
Runner Up A	Ireland	France ^		
Winner C	England	England	3rd Place	World Champions
Runner Up D	Wales $		Australia #	England &

$ Artificial neural networks with binary input and 4 or 8 middle layer nodes predicted Italy.

^ Artificial neural network with binary input and 4 middle layer nodes predicted Ireland.

Simulation package, binary logistic regression and multiple linear regression (satisfying assumptions) predicted France.

& Multiple linear regression (satisfying assumptions) predicted New Zealand.

Figure 5. Prediction for the knockout stage made using the computer-based methods.

Table 5 summarises the accuracy of the various predictions in relation to the actual results in the 2003 Rugby World Cup using the pre-determined evaluation scheme. As figure 6 shows, the average computer-based method had a higher evaluation score than the average individual human prediction but a lower evaluation score than that achieved by the expert focus group's prediction. There were three upsets in the pool matches where teams defeated opponents who were ranked above them in the Zurich World Rankings. These matches were Italy defeating Canada, USA defeating Japan and Uruguay defeating Georgia. The expert focus group and 9 of the individual human predictions successfully predicted all 3 of these upsets, an achievement that was not matched by any of the computer-based methods. The mean individual successfully predicted 1.86 ± 0.81 of the 3 upsets in the pool matches, which was only surpassed by one computer-based method; using multiple linear regression and satisfying its assumptions predicted 2 of the 3 upsets. However, the expert focus group predicted 3 additional upsets in the pool matches that did not materialise while the individual human predictions contained 3.23 ± 2.31 upsets in the pool matches that did not occur.

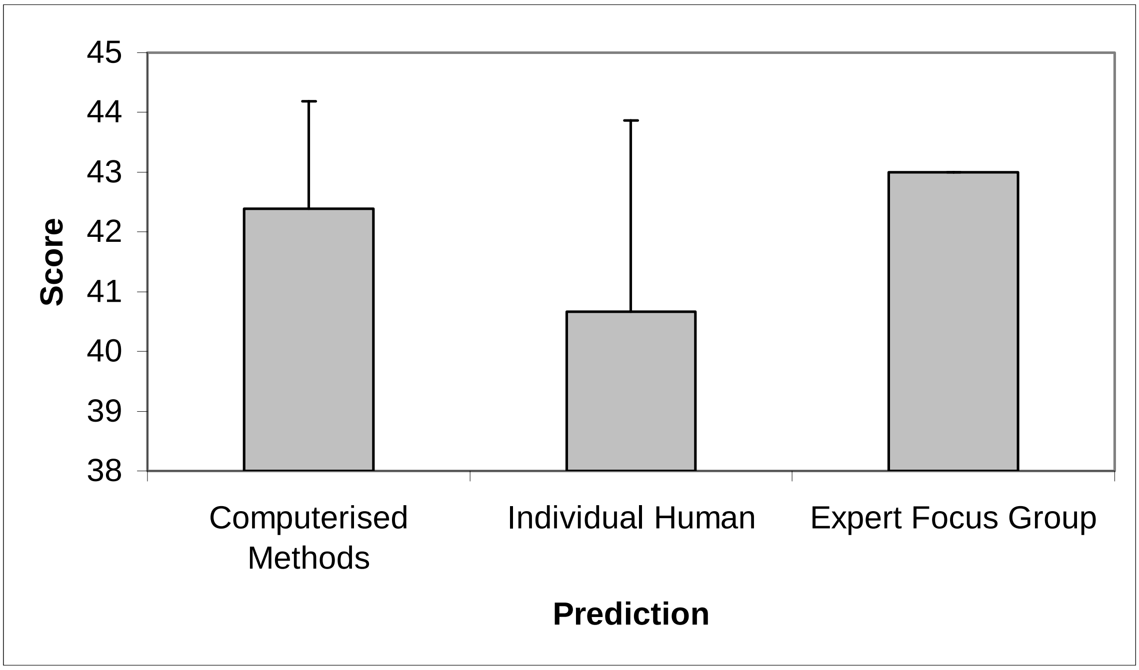

Figure 6. Prediction performance of human and computer-based methods.

All 37 pool matches that were won by the superior team were correctly predicted using the simulation model, the artificial neural networks with numeric input and the artificial neural network with binary input and a middle layer of 32 nodes. Indeed all of the computer-based methods did as well or better than the expert focus group and mean individual in predicting these 37 matches. All but 2 of the computer-based methods successfully predicted all 8 quarter-finalists in the correct pool finishing positions and all but 1 computer-based method predicted all 4 semi-finalists. However, none of the computer-based methods predicted that Australia would defeat New Zealand in the semi final. This semi-final was the one upset of the knock out stages and 12 of the 42 individual humans successfully predicted that Australia would reach the final. Five of the individual humans successfully predicted that England would defeat Australia in the final.

The computer-based predictions had many similarities and their evaluation scores ranged from 39 to 44.5 marks. The evaluation scores for the individual human based predictions were spread over a much wider range with one individual only getting two matches incorrect. There were 9 individual human predictions scoring 33.5 to 38 marks, which was below the range achieved by the computer-based methods. However there were 5 individual human predictions scoring 45 or 46 marks with the remaining 28 individuals scoring marks in the same 39 to 44 range as the computer-based methods.

The simulation model was the most successful computer-based method having gained more marks than the other computer-based predictions from the pool matches. The simulator used in the current investigation gave New Zealand a much lower chance of winning the tournament than England based on the combined conditional probabilities of them winning a potential quarter-final against South Africa, a potential semi-final against Australia and a potential final against England.

Table 5. Marks awarded for each prediction.

Method	Marks Awarded					
	Pool Matches (40)	Quarter-finals (4)	Semi-finals (2)	3rd Place Play Off (1)	Final (1)	Total (48)
1.1.1 Human-based methods						
Best Individual Human	39.00	4.00	2.00	1.00	0.00	46.00
Mean Human Prediction	35.63	3.45	1.17	0.26	0.31	40.66
Expert Focus Group	37.00	4.00	1.00	0.00	1.00	43.00
1.1.2 Computer-based methods						
Multiple linear regression (satisfies assumptions)	38.00	4.00	1.00	0.00	0.00	43.00
Multiple linear regression (violates assumptions)	38.00	4.00	1.00	0.00	1.00	44.00
Binary logistic regression	37.00	4.00	1.00	0.00	1.00	43.00
Neural networks with numeric input	37.00	4.00	1.00	0.00	1.00	43.00
Neural network with binary input – 4 middle layer nodes	34.00	3.00	1.00	0.00	1.00	39.00
Neural network with binary input – 8 middle layer nodes	34.00	4.00	1.00	0.00	1.00	40.00
Neural network with binary input – 16 middle layer nodes	36.00	4.00	1.00	0.00	1.00	42.00
Neural network with binary input – 32 middle layer nodes	37.00	4.00	1.00	0.00	1.00	43.00
Simulation Package	38.50	4.00	1.00	0.00	1.00	44.50

The accuracy of the artificial neural networks using binary input increased with the number of middle layer nodes included despite requiring fewer epochs per training match during the learning process. The artificial neural networks based on numeric input performed as well as the best artificial neural network based on binary input. There were no drawn matches in the 2003 Rugby World Cup validating the assumption made when using artificial neural networks as well as binary logistic regression. There were a total of 20 draws predicted for pool matches within the 42 individual human predictions.

The two multiple linear regression models disagreed about the results of 5 matches including an incorrectly predicted 3rd place play off between Australia and France and an incorrectly predicted final between New Zealand and England. The invalid use of multiple linear regression predicted an England win in the final which made this prediction more accurate with respect to the agreed evaluation scheme. There were 46 matches (excluding the 3rd place play off and the final) where the predicted points difference using the two regression models could be compared with the actual points difference when the matches were played. This also revealed that the version that violated the assumptions of multiple linear regression had a closer agreement to the actual scores in the matches; there was a greater relative reliability ($r = 0.769$ v $r = 0.667$) and a greater absolute reliability (SEM = 14.8 v SEM = 17.9) than the version that satisfied the assumptions.

Discussion

None of the predictions achieved the maximum score of 48 marks. However, given that the evaluation scores are out of 48, it is clear that predicting the outcome of the Rugby World Cup is not as challenging as predicting the results of international soccer matches. The lowest scoring individual human prediction of 33.5 points out of 48 was a far higher success rate than any occurring in a prediction exercise for Euro 96 (Buchner *et al*., 1997). All of the computer-based methods successfully predicted at least 7 out of 8 quarter-finalists, 3 out of 4 semi finalists and 1 of the 2 finalists. This was much more successful than the prediction of the knock out stages of the 2002 FIFA World Cup for soccer undertaken using similar methods (O'Donoghue *et al*., 2003). The expert focus group in the current investigation also predicted the knock out stages of the 2003 Rugby World Cup more successfully than a focus group that predicted the 2002 FIFA World Cup for soccer (O'Donoghue *et al*., 2003). There are two explanations for international rugby union matches being easier to predict than international soccer matches. The first of these is that drawn matches are very uncommon which gives a greater probability of correctly predicting a match outcome by guessing than would be the case in soccer where all three outcomes are common. The second explanation is that scoring is more frequent in rugby union than in soccer, which makes upsets less likely than in soccer.

There were three types of predictions made and evaluated during the current investigation; computer-based predictions, individual human predictions and the prediction of an expert focus group. All three types of prediction method had some successes over the others within the prediction exercise. The better accuracy of the computer-based predictions over the average human predictor agrees with the findings of Buchner *et al*. (1996) who found that predictions based on evidence theory were more accurate predictions of Euro 96 soccer matches than human predictions. The strength of the computer-based methods was in their objectivity; they were free from personal bias and subjective perception associated with human reasoning. The main disadvantage of the computer-based methods was their reliance on three numerical factors (one of which was synthesised during a peer review exercise) to the exclusion of all of the other factors relevant to international rugby union performance. The expert focus group and individual human predictors were able to draw upon a wealth of information ranging from facts and figures to more complex and rich qualitative knowledge. This allowed these methods to successfully predict more upsets than the computer-based methods but was also responsible for these methods incorrectly predicting upsets as well.

The simulation package was the most successful of the computer-based methods, which was also the case when similar methods were used to predict the 2002 FIFA World Cup for soccer (O'Donoghue *et al*., 2003). The simulator used by O'Donoghue *et al*. (2003) predicted that Brazil would win the soccer World Cup while recognised that France was the strongest team in the tournament. O'Donoghue *et al*.'s (2003) simulator favoured Brazil because France had a more difficult group and would have faced a more difficult second round opponent than Brazil's potential second round opponents had France qualified. The combination of conditional probabilities for qualifying from the group stages and progressing at each knock out stages revealed that Brazil had a greater chance of winning the tournament. In the current investigation, the simulator gave New Zealand a much lower chance of winning the World Cup than England for a similar reason. New Zealand's world ranking points were marginally lower than England's and the tournament was being played in Australia which was closer to New Zealand than England. New Zealand would need to win a potential quarter-final against South Africa, a potential semi-final against Australia and a potential final against England to win the tournament. However, this combination of conditions did not reduce New Zealand's chances sufficiently, according to the simulator, for Australia to have a greater chance of making the final. None the less, it should be recognised that the simulator allows for chance and provides probabilistic information that is necessary when predicting the outcome of a whole tournament before it starts. The simulator was based on a model that used the same three match factors as the other computerised methods. However, the modelling of different score types (tries, conversions, penalties and drop goals) instead of points difference may have influenced the results of this study. This is because there are many different score lines of the same points difference (20-0, 30-10, 40-20, and so on) that can be represented by the simulator where as the other methods could not distinguish between these different score lines.

The binary logistic regression and linear regression based predictions formed models based on historical data. The modelling process tended to recognise the proportion of upsets that would occur and then it would be those future matches where the gap between the strengths of the two teams was narrowest that would be predicted as upsets. There is not enough evidence within the current study to justify taking a relaxed view of the assumptions of multiple linear regression. The difference between the marks achieved by the predictions that satisfied and violated these assumptions came down to the final match. The version that satisfied the assumptions predicted that England would narrowly lose in the final (by 1.56 points). Indeed, the actual final was decided in extra time.

Artificial neural networks have been found to be beneficial in recognition and classification tasks including speech recognition (Keating et al., 1995). More recently, the Dynamic Control Network (DyCoN) has been used to analyse time series of playing area location data in soccer, volleyball and squash (Perl, 2001; Perl, 2002). The current investigation used three quantitative factors to allow a direct comparison with statistical methods and the simulation package. This study has also identified information of a qualitative nature that has assisted human based predictions. Given that artificial neural networks are commonly used to analyse complex information, future work should explore ways of incorporating more complex performance information into performance prediction tasks. The use of this type of data could lead to artificial neural network methods making different forecasts for international rugby union matches to the other quantitative methods. It is possible that by exploiting the strengths of fuzzy logic for modelling the uncertainty of sports performance, could lead to more accurate predictions being made by artificial neural networks. Much more research is needed to identify the complex information to be included, how it can be represented and pre-processed, whether the predictions become more accurate and indeed whether that accuracy approaches that of the best human predictors.

The current predictions used information known before the matches started but did not use process indicators of rugby union performance. While these may be unknown for the individual matches being forecasted, teams can be characterised by their style of play and typical tactics. Hughes et al (2001) describe how stable performance profiles can be developed to represent team performance in terms of process indicators. Such information could strengthen the quantitative models described in the current study. This would allow the ideas expressed by McGarry *et al*. (2002) to be incorporated into the prediction methods. Their work is fundamentally different to the current study in that they analyse internal aspects of matches whereas the current study used whole matches to analyse a tournament situation.

Conclusions

Rugby union is an easier sport than soccer to predict the outcome of matches for because there is a greater amount of scoring in rugby union. The most successful computer-based method was the simulation package which produced a prediction that recognised the effect of combined conditional probabilities on the overall outcome of the tournament. Computer-based prediction methods were more successful at predicting results than most of the predictions made by individual humans which were based on qualitative analysis. However, the expert focus group demonstrated that human expertise still exceeds that of machine based methods.

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The Visualization Multimedia Design Model - A New Approach to Developing Personalized Mental Training Technological Tools to Enhance Elite Athlete Performance

Chris Chisamore, Larry Katz, Dave Paskevich, Gail Kopp

University of Calgary

Abstract

Providing an athlete with the mental tools necessary to build, maintain or regain confidence can aid the athlete in achieving peak, or optimal performance. Many of the procedures and practices in mental training involve technology. This technology, ranges from digital video and audiotapes, to simulations and virtual reality. In this article the authors review the areas of sport efficacy and sport technology as they relate to athlete performance. The Visualization Multimedia Design Model (VMDM) is then introduced as a theoretical base for designing personalized technological mental training tools. These tools can be used by elite level athletes to help them mentally prepare for competition and peak athletic performance.

KEYWORDS: SPORT TECHNOLOGY, SPORT PSYCHOLOGY, INSTRUCTIONAL DESIGN, MENTAL TRAINING, PERFORMANCE ENHANCEMENT

Sport, Efficacy, and Technology

There is a constant search for methods to improve athletic performance, both physical and mental. Constantly improving equipment and physical training regimes, combined with increasingly popular mental training plans, allow today's athletes to produce results faster, higher and stronger than ever before. Mental skills training can provide the added dimension athletes require to prevail through a variety of mental issues such as adversity, pressure, low self-esteem, stress and tension, as well as confidence and efficacy. Athletes must be confident in their abilities in order to have the mental edge over those experiencing self-doubt. The right frame of mind helps athletes to perform to maximum ability. Techniques used to help put an athlete into the right frame of mind include arousal regulation, imagery, self-confidence, goal setting, and concentration (Weinberg & Gould, 1999). A variety of technological tools have been used with athletes to increase and enhance their performance. ranging from improvements in equipment and facilities to multimedia training tools and environments. The purpose of this paper is to discuss how technology can be used to enhance self-confidence/self-efficacy in athletes, as well as overall athletic performance through the use of sport psychology, technology, and proper instructional design.

In this paper a number of technological tools are identified, their uses outlined, and their effectiveness discussed. This is followed by a description of a new design model for technological tools to enhance confidence/efficacy and athletic performance. The Visualization Multimedia Design Model (VMDM) is an integration of previous research on sport technology, sport psychology, and the theories and principles of instructional design. Issues surrounding the use of such technology are also discussed.

Findings on Efficacy and Performance in Sport

Self-confidence and/or self-efficacy can be determining factors in how well an athlete performs. Goldberg (1998) suggested that one of the steps to achieving peak performance is "building self-confidence" (p. 199). Studies of elite athletes by: Mahoney, Gabriel, and Perkins (1987); Durand-Bush and Salmela (2002); Gould, Dieffenbach, and Moffett (2002); and, Gould, Guinan, Greenleaf, and Chung (2002); found that self-confidence was one of their most distinguishing characteristics.

A study by Vealey (1986) separated the term confidence into "trait and state sport-confidence" (p. 222). Trait sport-confidence (or self-confidence) is how an athlete generally feels about his/her abilities and capabilities. State sport-confidence (or self-efficacy) refers to how confident an athlete feels about those same abilities/capabilities in at a specific moment in time. These concepts of "trait" and "state" distinguish "confidence" from "efficacy".

Self-efficacy as a concept has been popularized by the work of Bandura (1982, 1990). Bandura commented on the power of the self-efficacy theory by stating that, "If self-efficacy is lacking, people tend to behave ineffectually, even though they know what to do" (Bandura, 1982, p. 127). He also observed, "the higher the level of perceived self-efficacy, the greater the performance accomplishments" (Bandura, 1982, p. 127). His theory of self-efficacy has come to dominate the thinking of many sport psychologists and mental training programs.

Some examples of the more than sixty studies (Feltz & Lirgg, in Singer, Hausenblas, & Janelle, 2001) which have tied increased levels of efficacy to improved performance include: Beauchamp, Bray, and Albinson, (2002); Lowther, Lane and Lane, (2002); Short et al., (2002); Chase, Lirgg, and Feltz, (1997); McKenzie and Howe, (1997); Lirgg and Feltz, (1991); Gould, Hodge, Peterson, and Giannini, (1989); McAuley, (1985); Weinberg, Yukelson, and Jackson, (1980); and, Weinberg, Gould, and Jackson, (1979).

Given the general acceptance of the theory of self-efficacy and its applications to sport, a number of studies have implemented some, or all, of Bandura's four self-efficacy sources of information: performance accomplishments (Chase et al., 1997; Feltz & Lirgg 1998; Beauchamp et al. 2002); vicarious experience (i.e., self-modeling) (Cox, 2002; Morey Sorrentino, 2000; Singleton & Feltz 1999, in Singer et al., 2001; McAuley, 1985); verbal persuasion (Kendall, Hrycaiko, Martin, & Kendall, 1990; Amirault, 2000); and finally, emotional arousal (Gould et al., 1992a, 1992b).

According to Bandura, those who have a strong sense of efficacy, "visualise success scenarios that provide positive guides for performance" (Bandura, 1997, in Beauchamp et al., 2002, p. 698). One particular approach to athlete preparation using the concept of modeling and imagery (Visuo-Motor Behavior Rehearsal, VMBR) was created by Suinn (1972a, 1972b, in Hall & Erffmeyer, 1983). VMBR consisted of (a) an initial relaxation phase, (b) visualizing performance during a specific stressful situation, and (c) performing the skill during the simulated stressful situation (Hall & Erffmeyer, 1983). Weinberg, Seabourne, and Jackson (1981) reported successful use of the VMBR model with karate performance.

Hall and Erffmeyer (1983) slightly adapted this procedure to include technology, adding videotaped model performances prior to the visualization techniques. Positive results were also gained. Wann (1997) stated "watching the tape had a more dramatic impact on performance than imagery training alone … the use of more traditional imagery techniques may be limited … some sort of visual aid that may assist in the process of image formation" (p. 83).

Findings on Technology and Performance in Sport

Many new and creative coaching practices involve technology. While the application of technology to sport is not a new phenomenon, recent advances in computer technology have sparked the imaginations and creativity of many. Paul Allen, a cofounder of Microsoft Corporation and owner of the Seattle Supersonics stated that, "the only thing holding back sports simulation products is the level of reality … realistic athlete-like or coach-like experiences that you can share with others on-line, in a real-time environment, are just sitting there over the horizon" (Haggerty, 1997).

A number of technological tools are currently available to help athletes enhance their performance. One recent innovation is the use of biofeedback devices (e.g., heart rate (HR) monitors and electroencephalogram (EEG) measures). Radlo, Steinberg, Singer, Barba, and Melnikov (2002) stated, "Using such psychophysiological measures as EEG and HR can help to provide a better understanding of why a performer can have a "mental edge" over an opponent when using a particular cognitive strategy" (p. 213). Other sport-related technology ranges from simple audio/visual tools, to leading edge simulation/virtual reality technology.

Audio

A review by Karageorghis and Terry (1997), of thirty-four studies examining the effects of music in sport and exercise provided numerous observations. As a conceptual framework, Karageorghis and Terry (1997) stated, among other findings "…music can alter psychomotor arousal and, therefore, can be used either as a stimulant or a sedative prior to and during physical activity" (p. 55-56).

Focusing on this concept, Karageorghis and Terry (1997) observed, "… sport psychologists often recommend music as part of a psych-up strategy in preparation for competition, or to calm overanxious athletes" (p. 57). Gfeller (1988, in Karageorghis & Terry, 1997) proposed that music would influence arousal if an extra-musical association were made:

"The sound promotes thoughts that inspire physical activity or promotes relaxation … (or) can act as a potent stimulus … this can be attributed not only to the inherent musical characteristics, but to the influence of elements of popular culture, such as cinema, television, and radio … (the media) may function as a conditioned stimulus eliciting a conditioned psychophysical response from athletes" (p. 57).

An important observation is the fact that the type of music can directly impact its effectiveness. Karageorghis and Terry (1997) observed that, "social class, ethnic background and peer group background" are among a number of factors that might influence how participants in music research studies reacted to particular types of music (p. 64). It seems critical that appropriate music be selected for a particular athlete.

Lanzillo, Burke, Joyner, and Hardy (2001) studied the effects of an individuals' favorite music on pre-performance confidence and anxiety levels. Lanzillo et al. (2001) stated that music listening "wards off boredom and anxiety; and when focused on, can induce flow experiences" (Cskiszentmihalyi, 1990, in Lanzillo et al., 2001, p. 102). According to the authors, "The 1999 Stanley Cup Champion Dallas Stars had a team warm-up music tape which led Brett Hull to say, 'You need hard-driving music before a game' " (Hull & Swift, 1999, p. 70, in Lanzillo et al., 2001, p. 103). Research findings by Lanzillo et al. (2001) concluded, "(an athlete's favorite) music significantly enhanced feelings of pre-competitive state self-confidence" (p. 108).

Other uses of audio technology include taped scripts of relaxation and/or hypnotic suggestion/autosuggestion to help enhance human performance (Orlick, 1990). Orlick (1990) outlined how scripts are used during repetitive suggestion. Short, powerful and positive scripts are spoken and repeated either by the athlete, or more effectively and efficiently using "tapes, (and) tape player" (Orlick, 1990, p. 118).

Likewise, a series of hypnosis studies by Pates (Pates, Maynard, & Westbury, 2001; Pates, Oliver, & Maynard, 2001; Pates, Cummings, & Maynard, 2002) has used recorded audiotapes to successfully reinforce certain positive mental triggers created in a hypnotic state and thereby improve performance.

Video

Video is also used by athletes and coaches in numerous ways. One area where video has impacted the cognitive side of sport and sport performance is in the attempt to improve athletes' perceptual and decision-making skills. A number of these studies in different sports included: football (Christina, Barresi, & Shaffner, 1990; Damron, 1955; Londeree, 1967, in Starkes & Lindley, 1994); tennis (Haskins, 1965, in Christina et al., 1990); baseball (Burroughs, 1984, in Christina et al., 1990); hockey goaltenders (Salmela & Fiorito, 1979; Sinclair & Moyls, 1979); soccer goalkeepers (Franks & Hanvey, 1997; Franks, 2000, in Lieberman et al., 2002; Savelsbergh, Williams, Van Der Kamp, & Ward, 2002); and, ice hockey (Thiffault, 1974, 1980, in Starkes & Lindley, 1994). In each of these studies videotaped plays and actions were presented to the subject, who in turn decided on a corresponding reaction. Significant results were reported in each of the studies. Starkes and Lindley (1994) indicated that, "video simulations are probably the best for training decision making" (p. 214).

Other video based studies highlighted the use of vision technology used to track eye movement and determine information gathered for ensuing decisions being made (Vickers & Adolphe, 1997; Adolphe et al., 1997, in Liebermann et al., 2002). Similarly, head-mounted cameras have also been used to record performance during orienteering competitions (Walsh, 1997; Omodei & McLennan, 1994). The recorded performance, from the athlete's actual perspective, is then available for analysis by both athlete and coach.

Two separate studies dealing with sport psychology consultants' work with NHL teams highlighted some of the other uses of videotape. Botterill outlined, "the use of visualization/imagery to maintain confidence, decrease worry, and facilitate readiness and development was illustrated through videotape" (Botterill & Orlick, in Botterill, 1990, p. 361). Additionally, "video/audio products were situationally used to help facilitate development and preparation (of both physical and mental skills)" (Botterill, 1990, p. 363).

Likewise, Halliwell (1990) provided a number of sport psychology services to elite hockey players to improve mental skills. Halliwell (1990) observed,

"Confidence is an elusive state of mind for many professional hockey players, … by combining peak performance music videos with visualization techniques, players are able to play with confidence and consistency for longer periods of time" (p. 371).

In creating these videos, Halliwell (1990),

"Ask(ed) the players to identify best games, best shifts, and periods of time when they were really on top of their game … (also, the players) identify favorite songs and, with the help of an audiovisual technician and a computer program, we then edit and synchronize the players' best game performances" (p. 371).

Another tool that is impacting sport and performance is digital video and its many associated analytical software tools and techniques. Straub (2003) observed, "Digital video technology is changing the face of sport psychology and coaching. In particular, the use of mini digital cameras and computers has revolutionalized the way coaches and sport psychologists interact with individual players and teams" (Retrieved March 13, 2003 from www.thesportjournal.org/sport-supplement/Volume11/sport-supplement-digital.htm). Many software packages are currently available, designed to record, edit, compile and organize video as never before. Such technology also offers the possibility of use with computer and Internet technology.

Ives, Straub, and Shelley (2002) highlighted an additional reason for maximizing digital technology, “the relative simplicity of digital video makes it more practical for sport psychology consultants to take advantage of these benefits” (Ives et al. 2002, p. 239). Included in the diverse number of tools that can quickly and easily produced using digital video were: instructional, assessment, and motivational clips, instructional and assessment full length videos, self-review and self-assessment videos, post-game clips, visualization tapes, season-end highlight and recruiting tapes, use of video to improve cognitive and perceptual skills, anticipatory and decision making video training, and finally, athlete evaluation. While none of these tools can be seen as particularly new or novel, the advent of digital technology has placed the possibility of creation directly into the hands of athletes, coaches, sport psychologists, and sport psychology consultants.

Simulation/Virtual Reality

An even more advanced tool being used to help athletes improve their performance is the application of simulation and/or virtual reality (VR) technology. Some studies involving simulation/VR technology are: teaching downhill skiing using a VR simulator (Li, 1993, in Haggerty, 1997); virtual golf simulators (Puttre, 1993, in Haggerty, 1997); VR exercise equipment (Maldari, 1997, Zedaker, 1997), and table tennis (Todorov, Shadmehr, & Bizzi, 1997). Liebermann et al. (2002) also cited several products that simulated real environments: cycling (CompuTrainer™, RaceMate Inc.), golf (Part-T Golf ™), and windsurfing (Force4 WindSurf Simulator, Force4 Enterprises Inc.)

Other examples of VR-sport related research included a study by Viskic-Stalec and Katovic (2001) in which a virtual environment for skydivers was created in order to train users on visualization techniques and patterns in 3D space. Additionally, a realistic VR dinghy sailing simulator was developed by Walls, Bertrand, Gale, and Saunders (1998). Walls et al. (1998) observed, “The test enables, for the first time, the ability to analyze the components of a sailor’s technique under laboratory conditions” (p. 69).

As previously highlighted, visualization (or mental imagery) has been shown to be an effective way to produce feelings of self-efficacy. Levy, Morey Sorrentino, Katz, & Peng (2002) used virtual reality to help speed skaters with visualization, familiarization and mental preparation for the 2002 Olympics. Using VR to create a virtual environment of the Salt Lake City Olympic Oval was deemed to be useful in helping the skaters to familiarize themselves and better mentally prepare. The resulting post-Olympic feedback highlighted some of the benefits and shortcomings of the current technology.

All of the athletes were satisfied with the realism of the virtual environment. According to Levy et al. (2002) one skater commented, “using the virtual Oval was like doing visualization with his eyes open” (p. 3). Other skaters also felt the virtual environment helped them with their visualization as they did not have to rely on their own imagery abilities. As a result, most of the skaters reported being less anxious leading up to the competition.

Apart from the visualization and familiarization training aspects of the simulation, the athletes also expressed a desire to be able to use the tool as a training device to help develop improved visualization skills and/or to run through race strategy/simulations. Levy et al. (2002) suggest that virtual reality has a place in the preparation of athletes for competition, specifically when used in conjunction with sport psychology and the athletes’ mental preparation”

A final example of simulation/VR tools being used in sport is the creation of the bobsled simulator by Kelly and Hubbard (2000). Attempting to re-create as many of the sensory feelings a bobsled driver would feel, Kelly and Hubbard's (2000) simulator included visual, vestibular (motion sense), tactile (feel of the controls) and auditory feedback. Kelly and Hubbard (2000) concluded, "Results confirm the agreement between the simulator and reality for a typical run at Salt Lake City and the capability of the device as a useful training device" (p. 24).

Enhancing Efficacy, Confidence and/or Performance with Technology

The current range of diverse technological tools available offers the developer of any kind of athlete training tool (i.e., a sport psychologist, sport psychology consultant, trainer or coach) a highly dynamic and multidimensional "toolkit" from which to choose. Technologies can be used singly, or combined into potentially even more effective and powerful training systems.

Traditionally, mental skills training associated with self-confidence/self-efficacy has been a practice most athletes carried out predominantly inside their minds. As Orlick (1980) explained, "Mental imagery is actually a form of simulation but the simulation takes place entirely in your head" (p. 88).

As a precursor to technology-enhanced visualization environments, Vealey (in Williams, 1986) reported how prior to the 1976 Summer Olympics, representatives from the Soviet Union shot pictures of the facilities to show to their athletes back in the U.S.S.R. Athletes, in turn, used the pictures to create images of themselves performing in those facilities and to familiarize themselves with the Olympic environment before they arrived (p. 211). Orlick (1980) also agreed that for athletes having difficulty imaging, props could be used or semi-simulations attempted (i.e., a walk through of the upcoming performance).

Amirault (2000), Botterill (1990), and Halliwell(1990) used a number of techniques and practices to maintain and/or enhance mental toughness and optimal performance among elite level hockey players. Tools used and created included video and/or audio products for such things as self-talk, relaxation, focusing, and confidence building.

Stredney (1993) examined how and why pictures/images are used and what VR offers over other media. "By creating more sophisticated imagery, we may facilitate the brain's ability to assimilate novel information by introducing cues that establish links to internally held contexts" (Stredney, 1993, p. 324). Stredney (1993) also stated,

"We should take advantage of the flexibility of the computer and create interfaces that allow the user to individualize their environment in order to augment their mental capacities. In this way, the user can create the level of realism which provides the visual schema that best suits their understanding and transfer of new information" (p. 324).

It appears that new options and training tools are evolving with regard to mental training, taking the traditional internal visualization done inside the athlete's mind and enhancing it with audio visual prompts. However, as with any training tool, proper analysis, development, and design are critical to overall success.

The Visualization Multimedia Design Model a New Approach to Developing

Mental Training Tools

The term "Visualization Database" has been used to refer to the mental training tool(s) that can be developed using this design model. Just as a database is a collection of data which can be accessed and retrieved easily and quickly, so too, does this mental training tool contain a number of media elements/data, which can be accessed by the athlete whenever desired. This collection of media would also be personalized to the needs of the individual athlete based on a formalized needs analysis process combined with applied theories and principles of sport psychology such as visualization (Cumming & Hall, 2002; Martin, Moritz, & Hall, 1999), and theories of instructional systems design (Dick & Carey, 1985). Each tool would be comprised of a variety of media (e.g., music, images, video, audio, text) tailored to the needs and learning styles of the athlete to assist in preparation for optimal performance.

VMDM Theoretical Foundations

Through coaching and training an athlete's actions are behaviorally conditioned to occur (e.g. a goaltender's reaction to an incoming puck, or a baseball player's reaction to a ball coming off a bat). There are other instances where athletes must process the information of their environment in order to make decisions about what actions/reactions will be undertaken. Tactical and strategic situations require the athlete to input environmental information, process it, and then output the proper decision(s).

The complexity and dynamics of sports implies that players will not process information equally in order to put the proper skills, techniques, tactics and strategies into use. Decisions made (or not made) and actions taken (or not taken) reflect individual differences, knowledge, experiences, and/or capacities of athletes. In order to maximize the performances of an athlete and/or team, these differences should be acknowledged, analyzed, addressed and provided for so that each and every athlete can have the potential to compete at his/her highest possible level and reach his/her training and development goals and objectives.

In order to develop training programs that accommodate individual learning styles, aspects from three major theories of learning (Behaviorism, Cognitivism, and Constructivism) should be considered.

The Behaviorist approach, which includes B.F. Skinner's research on shaping behavior (Operant Conditioning), supports the notion of reinforcing an athlete's reaction/response to particular stimuli. Repeated over time, this behavior becomes conditioned to occur (Retrieved December 5, 2003, from http://tip.psychology.org/skinner.html). This approach is popular with coaches who apply drill and practice to the development of skills and tactics.

On a more individualized level, behaviorism has also led to Keller's Individualized Instruction and Program for Learning in Accordance with Needs (PLAN). Key elements of the Keller PLAN include:

1. Go-at-your-own-pace (so students can proceed according to their abilities, interests, and personal schedules);
2. Unit-perfection requirement (which means students must demonstrate mastery of a unit before proceeding to other units);
3. Lectures and demonstrations for motivation (instead of for communication of critical information);
4. Stress on the written word for teacher-student communication (which helps develop comprehension and expression skills); and,
5. Tutoring/proctoring (which allows repeats on exams, enhanced personal-social interaction, and personalized instruction) (Retrieved December 5, 2003 from http://ei.cs.vt.edu/~mm/s96/cs4984Format/subsection3_2_1.html).

These elements of behaviorism have been incorporated into the VMDM, thus enabling the athlete/coach/designer to develop a personalized, self-paced training tool.

Also within the VMDM are a number of ideas taken from the cognitivist domain. The cognitivist approach to learning (input-processing-output) is an important component in sport where athletes must be able to process information quickly and react.

Gagne and Briggs' research on cognition focused on how the mind inputs, processes and outputs information. Sensory inputs are processed and placed into short- or long-term memory where, depending on the way in which they were programmed, they are either forgotten or retrieved when needed. Thus, the type of information inputted to be processed becomes a determinant factor in whether the mind stores it for further use or discards it. For the purpose of the VMDM, this means that the model must be able to develop a training tool complete with task-relevant and potentially motivational information that the athlete deems important enough to place into long-term memory for future retrieval. Developing an efficient mental training tool (containing multi-sensory information) based on the VMDM makes use of Gagne and Briggs' CIP work.

In addition to CIP, Gagne developed Conditions of Learning (Retrieved December 5, 2003 from http://tip.psychology.org/gagne.html), which referred to classifying the different types of learning that occur. Gagne identified five major categories of learning:

1. Intellectual
2. Motor Skill
3. Verbal Information
4. Cognitive Strategy
5. Attitude

These differ slightly from the three domains of learning identified by Bloom (Retrieved December 5, 2003 from http://www.nwlink.com/~donclark/hrd/bloom.html):

1. Cognitive
2. Affective
3. Psychomotor

Just as there are different types of learning that occur, so too, individual learners have different styles and/or preferences for learning. Gardiner's research into the Theory of Multiple Intelligences (1997, in Reigeluth, 1999) addressed this subject by stating that there is no single intelligence, not everyone learns in the same way. Gardiner determined that there were actually eight information-processing mechanisms that all learners possess (although some are stronger than others):

1. Linguistic Intelligence
2. Logical-mathematical
3. Spatial
4. Bodily-kinesthetic
5. Naturalist
6. Interpersonal
7. Intrapersonal
8. Existential

Thus for the developer of instruction, it is important to design for different learners and their strengths/preferences in which they optimally process learning. The VMDM attempts to incorporate these ideas, as the final product developed through the model should be a reflection of the learner/athlete and his/her preferences/needs.

Another aspect of many learning situations is the motivational level of the learner. A general theory of motivation and learning is Keller's ARCS Model (1987, in Ely & Plomp, 2001), which attempted to ensure that learning encompassed the following properties:

1. Attention
2. Relevance
3. Confidence
4. Satisfaction

Gaining the learner's attention, providing meaningful/task-relevant information, giving the learner confidence and satisfaction with the learning, are all critical elements to many forms of instruction. Since the VMDM focuses on producing tools that optimally prepare athletes for competition, it is necessary to design in motivational structures for the end-user, the athlete.
As previously mentioned, an important motivational theory for sport and athletes is the theory of Self-efficacy (Bandura, 1990, 1982). The VMDM incorporates the four major sources of information through which self-efficacy can be developed:

1. Performance accomplishments (the experiencing of some type of success which supplies legitimate proof of ability and increased efficacy);
2. Vicarious experience (the use of modeled performance as a basis for successful execution of a skill);
3. Verbal persuasion (the need for helpful, realistic verbal persuasion by coaches, parents, peers or even self-persuasion/self-talk on the part of the athlete); and,
4. Emotional arousal (having the optimal level of emotional readiness to perform).

* More recently some researchers have added "emotional states" and "imaginal experiences" to this list (Feltz and Lirgg, in Singer et al., 2001, p. 341).
These elements are used in the VMDM through numerous means to stimulate and maintain efficacy. Some examples include:

Media Objects	***Example***	**Links to Bandura and/or Feltz & Lirgg**
From the athlete's personal life	Images, home movie clips of family, friends, loved ones etc.	Emotional States, Verbal Persuasion, Emotional Arousal
From the athlete's sport career	Audio/video personal highlights	Performance Accomplishments, Emotional Arousal
From performance environments	Images of performance venues from various perspectives	Imaginal Experiences, Vicarious Experience
To improve the athlete's mental skills and to help them be prepared for competition	Audio recordings of sport psych techniques and practices, video clips etc.	Performance Accomplishments, Emotional States, Verbal Persuasion, Emotional Arousal
On the knowledge, skills and attitudes of the athlete's sport	Images with text and/or voice overlay reminders for particular aspects of skill and/or technique	Vicarious Experience, Imaginal Experiences
A chronology of the athlete's mental skills development	An electronic record of the mental skills training program	

These ideas are incorporated into the VMDM, allowing for the creation of information packages which, based on the needs of the learner, addresses these issues of confidence/efficacy and motivation.
A final cognitivist theory that has been applied to the VMDM is the theory of situated cognition and cognitive apprenticeship (Brown, Collins, & Duguid, 1989, in Ely & Plomp, 2001). Situated cognition attempts to reduce or remove the separation between knowing and doing. Placed within context-specific, situationally relevant learning environments, the user/learner makes use of the necessary/required cognitive tools in order to solve the educational goal or learning outcome. This is tied to another term, cognitive apprenticeship, which essentially supports learning in a domain by enabling students to acquire, develop, and use cognitive tools in authentic domain activities. This includes use of such aids as situated modeling, coaching, and fading. (Retrieved December 5, from

http://www.astc.org/resource/educator/situat.htm). Using task-specific (or performance specific) information and environment stimuli is important to the VMDM through which learners use a designed tool to enable them to perform optimally in their performance environment(s).

Finally, several constructivist approaches have been used within the VMDM in order to more effectively compensate for learner differences and learning styles. Vygotsky's research concluded that there is always a learning gap between what a learner knows how to do/is capable of doing, and what the learner does not know how to do/is incapable of doing (see Fig. 1.2 & Fig. 1.3). With the proper learning situation, which can include coaching/assistance/scaffolding etc., the learner moves from not knowing to knowing. This period of learning is known as the Zone of Proximal Development and it is there that optimal learning occurs. This also becomes a continuous process for as the learner acquires new knowledge, the Zone of Proximal Development is pushed forward to new, unknown knowledge (Retrieved December 5, 2003 from http://www.ncrel.org/sdrs/areas/issues/students/learning/lr1zpd.htm). This is also the goal of the VMDM, building learning/instructional environments that stimulate optimal learning/preparation. The model also provides for the re-creation of the training tool, which in turn, like the Zone of Proximal Development, pushes the user's knowledge and capabilities to new levels.

In order for proper learning to take place, the VMDM allows for the creation of a type of constructivist learning environment following along the lines of the work of Jonassen's Constructivist Learning Environments (in Reigeluth 1999). In a Constructivist Learning Environment (CLE) the problem drives the learning and learners may direct themselves to any particular portion of the instructional environment. Traditional teaching roles and linear instruction are changed here in order to give the learners/users more control over what is being learned and in what particular way. Information resources, cognitive tools, and support (such as modeling, coaching and scaffolding) are all included in the learning environment, to be used by the learner as required. This is similar to the learning environment created through the VMDM, personalized, user-centered aids that are navigated and accessed by the user as required for optimal mental readiness prior to competition.

It is believed that by using a combination of learning theories, styles and models, a more powerful and effective final product can be created. Designing a model with components from a variety of approaches should help to better accommodate the target audience (high performance athletes) and their numerous learning styles and preferences.

Once the desired theories for the development of a new model have been identified and assimilated, the model itself must be created. The Analysis, Design, Development, Implementation, and Evaluation (ADDIE) Model for developing instructional packages, is fundamental to the process and field of instructional design (ID). While the ADDIE model has been criticized for simplicity and lack of depth, it nevertheless represents a high-level breakdown of what should be covered when attempting to design instruction for learners.

A more renowned model for instructional design is the Dick and Carey Model, widely used as a basis in the field of instructional design for all levels and types of training. Identifying goals and conducting an analysis is followed by development of objectives, tests, strategies, and instructional materials that is then followed by formative and summative evaluations and revisions. It can be seen that all of the outlined models contain many similar elements and components that are core to the process of instructional design. When designing a new ID model such concepts should be included in some shape or form regardless of the domain or field in which the model is to be used.

Overview of the VMDM

Figure 1.1 outlines the structure of the VMDM, which can be broken down into several phases identified as:

1. User Analysis
2. Development
3. Implementation
4. Evaluation/Re-design

Phase 1 – User Analysis

During the initial phase of the VMDM process, an analysis is done on the future user of the training tool. Information is gathered on the individual athlete and his/her mental skills training strengths and weaknesses. It is critical as this stage to understand what mental strategies and/or tactics are used by the athlete to become mentally prepared. The gathered information comes from the athlete themselves, coaches, sport psychologists (potentially, even family and/or friends), as well as the designer of the instructional tool. This information would then be analyzed for potential media objects and content. Multimedia technology could be used in numerous forms in order to facilitate this process. Some potential examples include:

Text	***Images***	***Audio***	**Video**	**Simulation/VR**
Phrases, inspirational quotes	Images of performance venues from various perspectives	Favorite music for emotional arousal	Video for decision-making training	Simulation of real performance situations
Technical, tactical and/or strategic reminders	Images clips of family, friends, loved ones etc.	Motivational messages	Video of personal highlights	Simulation of real performance venues
Self-talk phrases for confidence, hardiness, etc.	Images of personal heroes, celebrities, other athletes or the athlete himself/ herself	Key words/phrases spoken by the athlete/coach/ psychologist, etc.	Video highlight reels of other athletes	3D video of performance and/or training situations
		Sounds of the competition venue	Video for visualization/ imagery	Computer generated re-creation of performance venues
		Relaxation and/or hypnotic suggestions/ autosuggestions	Home movie clips of family, friends, loved ones etc.	

All of these media elements, designed and developed specifically for the needs of the athlete would be then packaged into an interactive CD or DVD format. Having such a portable training aid allows an athlete to take the program and use it almost anywhere. Since it is accessible through the CD or DVD player on an athlete's laptop computer, this tool could be used as often as necessary and wherever the athlete is training/competing.

Phase 2 – Development

Once the needs of the athlete have been determined from numerous sources, the corresponding media objects that could aid the athlete in his/her mental preparation are identified, discovered and or created. Subsequently, they are placed into numerous categories:

Categories	*Explanation*	*Example*
Personal	Media objects from the athlete's personal life	Images, home movie clips of family, friends, loved ones etc.
Highlights	Media objects from the athlete's sport career	Audio/video personal highlights
Venues	Media objects from performance environments	Images of performance venues from various perspectives
Mental Skills Training	Media objects to improve the athlete's mental skills and to help them be prepared for competition	Audio recordings of sport psych techniques and practices, video clips etc.
Coaches' Corner	Media objects on the knowledge, skills and attitudes of the athlete's sport	Images with text and/or voice overlay reminders for particular aspects of skill and/or technique
Logbook	A chronology of the athlete's mental skills development	An electronic record of the mental skills training program

These categories have been deemed generic enough to appeal to the basic needs of the majority of athletes. They can, however, be further personalized to the individual (e.g., categories could be expanded, combined, or even eliminated).

Phase 3 – Implementation

In this third phase of the design process, the created DVD media tool is implemented into the athlete's mental warm-up (or overall mental skills) routine. At this stage, the athlete can take full control of the training tool and how it is used. Since there are numerous media objects located within various categories available for use, it could be up to the athlete to determine what elements would be accessed and when. This constructivist approach to the use of the training tool provides for user control based on user needs at a particular moment in time (e.g., before a competition in a particular venue, versus a particular opponent, at a particular time in the season, and/or based on the current pre-performance mood of the athlete). An example of a hypothetical training session for a user is as follows:

Time	**Mental Skill**	**Media Object**
5 minutes	Relaxation breathing procedure	Audio track
10 minutes	Visualization program	Images of the performance environment with music
5 minutes	Strategic and Tactical information reminders	Images of performance situations with textual overlays and athlete's voice track
5 minutes	Energization element for Motivation	Images of admired people doing extraordinary things, with high-tempo music
5 minutes	Personal highlights for optimal Self-Confidence	Career and/or seasonal achievements, with powerful music

Phase 4 – Evaluation/Re-design

The final phase of the VMDM process is an evaluation/re-design of the effectiveness of the tool. This could be done at any stage after implementation and as often as is required due to potential errors in the initial User Analysis and/or Development or simply due to the changing needs of the athlete over time. In either scenario, the VMDM should provide for multiple re-designs of the product as the skills and needs of the individual continue to grow and/or evolve.

Design Issues

The VMDM requires the creation of multimedia training tools that involve the use of a vast number of media objects (e.g. video, music, photographs). One major area of concern pertains to the issue of copyright. This is especially true for obtaining examples of the athlete's performance(s) that are usually recorded by commercial broadcasters who may hold the copyright. Incorporating high quality music and pictures have similar issues.

From a technical perspective, there are the issues of compression of the audio and video information for transfer to digital storage, the implications of compression rate for available memory and quality of the final product (e.g. CD-ROM versus DVD). Consideration also must be given to the user interface, which needs to be easy to use, but still flexible enough to allow for the creation of themes and levels of selection. The program also has to be aesthetically pleasing in order to encourage the athlete to use it.

While the VMDM approach tries to individualize the process, many of the multimedia elements can be generic. Developing a multimedia database of accessible, generic objects could facilitate the process. Jennett, Hunter, Teixeira, Rankin, and Katz (2002) designed a database of multimedia learning objects that included "video/audio clips, texts, graphics, animation, documents, presentations, digitized video, and full course web sites." (p. 21). The repository included, "a shared user interface, a user authentication structure, a technical foundation of functional and system requirements for defining the elements, and an ongoing website focusing on the activity of the … project." (Jennett et. al, 2002, p.23). Key to the development of the database were a number of issues which included:

- Cross-platform capabilities,
- Keywords for proper object identification according to international standards,
- Ability to search the database effectively, and
- An intuitive interface for the user

A second study by Katz, Teixeira, Hunter, and Jennett (2002) also discussed the importance of identifying (tagging) objects so that they can easily be searched for, found, and used. This could be done effectively based on international standards such as the Dublin Core Metadata Initiative, or the U.S. Department of Defence and the White House Office of Science and Technology Policy's Advanced Distributed Learning (Katz et. al, 2002, p.13). Other issues discussed included:

- Incorporating different multimedia objects containing different formats and the potential need for plugins, with regards to online databases
- The need for particular Internet browsers (for online databases)
- Appropriate computer knowledge to operate the database,
- Proper recognition and/or credit for particular objects entered into the database and belonging to an individual and/or group (copyright), and
- The idea of quality control.

Quality control refers to the need for some type of control as to who can enter what objects into the database. This becomes critical when the database is being shared among a number of users with common access.

Katz et. al (2002) suggested that to assure the proper identification, cataloging/indexing and/or metatagging of database objects, "professional expertise and content familiarity … A trained team working under the coordination of an educational professional with knowledge in the domain" (p. 19) would be important.

Designing an athlete-specific database for the VMDM would be a good starting point for creating individual programs. For example, generic templates could be stored in the database for easy access. These standardized templates, by sport, would provide the basic framework for the creation of a VMDM.

Practical Constraints

Once a technology has been created it must be accepted and then used effectively and efficiently. Unfortunately, compared to other disciplines, many new and innovative technologies seem to be in the early stages of diffusion among, physical educators, coaches, athletes and/or sport psychologists/psychology consultants.

According to Raz-Lieberman (2000), possible reasons for explaining why using computer-based technology in physical education (and sport) has lagged behind other fields include the fact that there has not been a 'natural connection' between computers and physical education (compared to mathematics or science), attitudes (teachers, coaches, and athletes need more confidence and expertise in using computers), physical education is a 'practice subject' (physical education topics can be learned primarily by active participation, cognitive processes may play a more minor role) and finally, the availability of hardware and software (few schools have computers in the gym, at the swimming pool, or in the field).

As a result, some new ideas or products require lengthy periods before adoption. Rogers (1995) defines the Diffusion of Information Model as the "process through which an individual (or other decision-making unit) passes from first knowledge of an innovation to forming an attitude toward the innovation, to a decision to adopt or to reject, to implementation of the new idea and the confirmation of this decision" (p. 20). Based on Roger's theory, five distinguishable stages exist: knowledge of the innovation, persuasion about the innovation, decision as to use or not use the innovation, implementation and usage of the innovation, and confirmation or rejection of the innovation (Rogers, 1995).

Raz-Lieberman (2000) also cited a model for predicting technological innovation proposed by Davis (1989) and Davis et al. (1989) – the Technology Acceptance Model (TAM). The theoretical basis of the model is the Theory of Reasoned Action (TRA) that suggests that individuals' attitudes influence behavior and performance (Fishbein & Ajzen, 1975). TAM proposes causal relationships between the users' attitude, intention, and actual usage. The two main beliefs that will influence the person' attitudes and indirectly, his or her performance, are: perceived usefulness and the perceived ease-of-use of the innovation. Both Roger's Diffusion of Information Model and Daris's Technology Acceptance Model must be addressed if the VMDM is to be successful with athletes and coaches.

Another consideration is the time and expertise required to assemble the information. Whose responsibility is it to design and develop the materials? Should it be added to the coach's list of responsibilities? The athlete? A specialist?

Designing a relatively simple VMDM includes eliciting from the athlete what media objects are required, searching for the objects, and assembling them using a multimedia computer. Based on some prototype models developed for Canadian Mogul skiers (Chisamore and

Paskevich 2003) this process takes about ten hours per athlete. Would coaches have the time and/or resources to produce such tools for members of an entire team? Should the athletes themselves be responsible for the creation of their own tools? Or should outside design expertise be solicited to help with the creation of these tools? These are all issues which may be resolved on a coach by coach or athlete by athlete basis depending on factors such as an individual’s level of technical know-how, his or her access to appropriate resources, time availability and willingness to use the program.

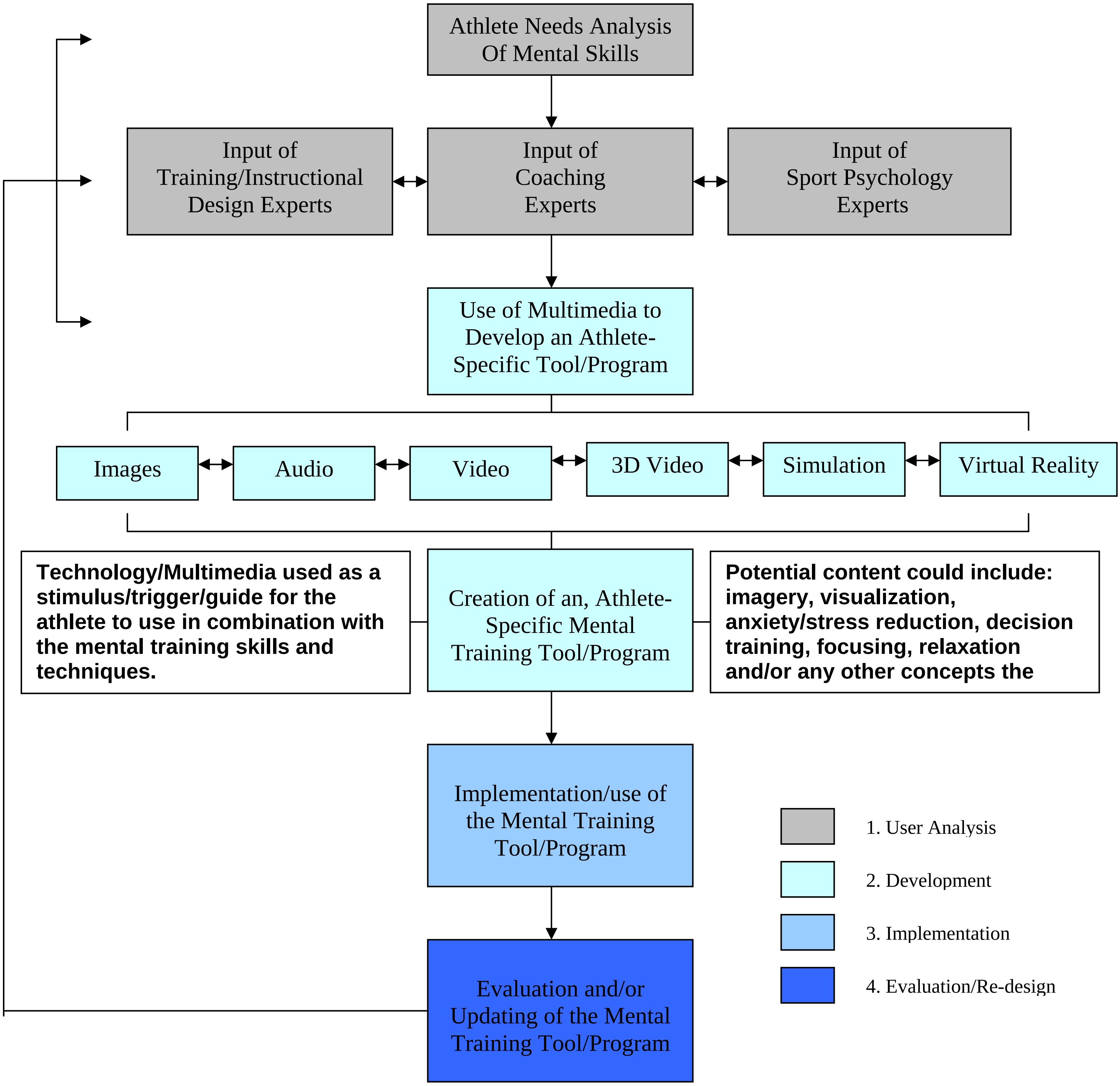
Given the time, resources, and energy required to develop and use such a resource, it must be beneficial. Researchers at the University of Calgary have undertaken a study to determine the effectiveness of using the Visualization Multimedia Design Model (VMDM) to create personalized multimedia, mental training aids for high performance athletes.

Summary

Research has shown that providing athletes with the mental tools necessary to build, maintain or regain confidence can aid them in achieving peak, or optimal performance. Efficacy was noted as a key element to mental preparation and performance among athletes. Technology is being employed in a multitude of ways to improve athletic performance. Many of the procedures and practices in mental training involve technology. Combining mental training and technology could help elite level athletes improve efficacy, mentally prepare for competition, and attain peak athletic performance. Building such tools and then customizing them to the needs of individual athletes as outlined in the explanation of the Visualization Multimedia Design Model, provides many exciting and potentially novel approaches to mental skills training. Combining psychological theories and principles with technical innovation and training design expertise allows for the creation of new training tools that are able to further improve the performance of athletes in a variety of sports.

As yet, little research has been produced to support or reject such projections. However, due to the exciting and potentially beneficial nature such applications present, the examination of such training practices seem warranted. Based on the outlined development model several Visualization Databases are being created and implemented with a number of high-performance athletes, thus, providing an opportunity for further testing and research.

Fig. 1.1. The Visualization Multimedia Design Model.



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The Mathematics and Physics of Body Surfing

Neville de Mestre

Bond University

Abstract

Waves on the ocean are generated well away from any shoreline and travel under a prevailing wind towards a distant shore. These deep-water waves eventually become shallow-water waves and break near the shore creating a turbulent surf front of bubbles, foam and spray, encompassing secondary breaking and smaller splashing waves. Human surfers can propel themselves shorewards on these breakers or broken waves; the skill being termed body surfing.

This paper analyses the breaker and its surf front and their effects on the surfer endeavouring to ride them shorewards. Various body-surfing techniques will be discussed, so that further scientific knowledge of this recreational art can be obtained.

KEY WORDS: BODY SURFING; SURF ZONE; OCEAN WAVES

Introduction

Humans probably swam in the Australian surf well before Captain Cook sailed up the East coast of Australia in 1770. Coastal aboriginal tribes undoubtedly ventured into the surf, but it is not recorded if they knew how to body surf. Hawaiian tribes were known to body surf well before the 19^{th} century. The first recorded body surfer in Australia was probably Tommy Tanna from the Marshall Islands who was employed at Manly about 1890. Tanna taught a few locals to surf at Manly, but it was not until William Goucher defied the law and entered the surf in broad daylight in 1902 that the art of body surfing began to develop in Australia (Galton, 1984).

Since then, Australians have learnt to travel shorewards on broken waves using boards, skis, boats, flippers, rubber tyres or almost any object that assists floatation.

Australian surfing has progressed rapidly since then. Together with Hawaiians, Californians, New Zealanders and South Africans, Australians lead the world in all forms of surfing; covering boats, skis, boards and the body.

The purest form of surfing is body surfing, where the surfer has only a swimming costume and his or her developed skills to handle the waves of the ocean breaking near the shore. Little scientific investigation has been carried out on body surfing and it is the aim of this paper to begin to rectify this.

Deep Water Waves on the Ocean's Surface

Most waves on the surface of the ocean are generated by winds and storms at sea. There are rare exceptions such as those generated by seismic disturbances and, with a lesser magnitude, those generated by surface vessels in motion.

After a storm or strong wind event, a ground swell of waves eventually emerges on the surface of the ocean travelling with a fixed period and wave length in a particular direction. When the average water depth beneath the wave is greater than half the wave length of this wave train, it has been observed that there is very little change to the wave characteristics and it is considered to be a deep-water wave (Bascom, 1959). The mathematical analysis of deep-water waves assumes that the water depth is infinite, and the associated deep-water wave theory can predict much of the behaviour of waves far out to sea, including the fact that they may break and re-form into smooth waves with less energy than they had before they broke. It is well known that the water particles, beneath and on the surface of a passing deep-water wave, travel in circular orbits as the wave train passes, but for the deeper particles these circular orbits have smaller and smaller radii until the movement is essentially negligible when the depth exceeds half the wave length. (Bascom, 1959)

The average characteristics of a wave within a wave train depend on the action time of the storm, the fetch (or distance) from the storm centre to the particular wave being observed, and the intensity of the storm or wind.

Of course, as a wave approaches the shoreline, its characteristics are known to change. Nevertheless, every observed wave has a primary set of characteristics in deep water with many smaller perturbations on it due to secondary small wave disturbances. Peregrine (1983) contends that when trying to understand and analyse the breaking of waves near the shoreline, each wave in the train can be considered basically as a solitary primary wave approaching the shore.

Shallow Water Waves

As the depth of water falls below half the wave length, the water-particle circular orbits near the bottom become modified to ellipses. The waves are then termed shallow-water waves, and it has been noted from nonlinear theory and many experiments that as the depth decreases, the wave length reduces, the height of the wave increases, the speed of the wave decreases, but the period remains constant (Whitham, 1967; Hotta and Mizuguchi, 1980).

To analyse these constantly changing, shallow-water waves mathematically, a number of simplifications are required.

The ocean is considered as an uncompressed inviscid fluid in a constant gravitational field. The Navier-Stokes equations for continuity and momentum are therefore

$$\nabla . \mathbf{q} = 0 \qquad (1)$$

and

$$\mathbf{q}_t + (\mathbf{q} \, . \, \nabla)\, \mathbf{q} = -\frac{1}{\rho} \nabla p - g\, \mathbf{j} \qquad (2)$$

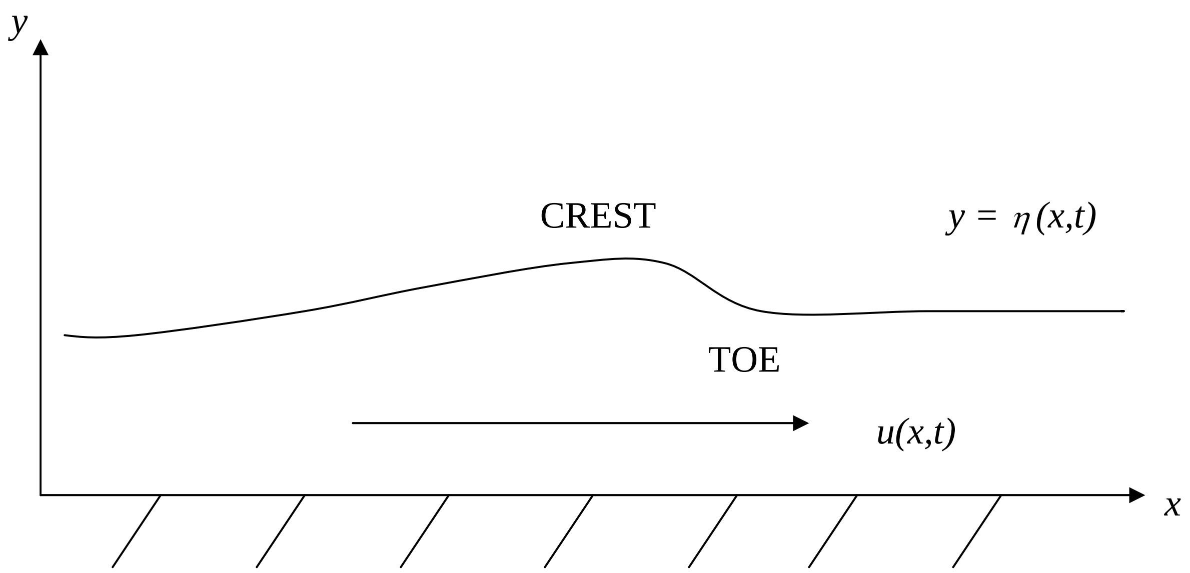

Figure 1. Wave Profile $y = \eta\ (x, t)$.

where p is the pressure, ρ is the constant density, g is the acceleration due to gravity, and **j** is a unit vector vertically upwards. The velocity vector **q** = (u, v) is assumed to be two-dimensional for this simplified model, where u is in the direction of wave motion towards the shore and v is the vertical component.

Shallow water theory assumes that the vertical component of equation (2) can be approximated by

$$-\frac{1}{\rho}\ p_y - g = 0$$

Hence $$p - p_\circ = \rho\, g\,(\eta - y)$$

where $p_\circ$ is atmospheric pressure on the water surface $y = \eta\ (x, t)$. The horizontal component of equation (2) then reduces to

$$u_t + uu_x + g\,\eta_x = 0 \qquad (3)$$

while the free-surface boundary condition is

$$\eta_t + u\,\eta_x + \eta\, u_x = 0 \qquad (4)$$

(see Whitham, 1974).

This model does not include the drag of the water particles on the bottom, and instead tries to predict the behaviour of the changing wave through the non-linear convection terms. These equations for finite-amplitude shallow-water waves essentially assume that water-particle accelerations are negligible compared with gravity or, in other words, that the pressure at any point in the wave is hydrostatic. This is certainly not true just before the wave breaks, but it is a strength of this model that even for water of constant depth, the mathematical solution indicates a steepening of the front of the wave. This arises because each water particle with Eulerian velocity u has a Lagrangian velocity $u + [g (D + \varsigma)]^{1/2}$, where D is the undisturbed water depth and ς is the elevation (positive or negative) of the water particle relative to this depth. Therefore, the higher parts of the wave travel faster, and the wave will eventually overturn or break.

The only mathematically tractable solution of the above equations is for small amplitude waves using a perturbation analysis to include the non-linear effects. The resulting equations are called the Boussinesq equations and have been used for gently sloping bottoms as well as for the constant-depth situation (Whitham, 1974). It appears from this mathematics that the waves will break when their height H is almost as great as the undisturbed depth D. The ratio D/H in the range 1.1 to 1.3 is often termed the “breaker index”. In the simplest case of steady waves normally incident on a beach, it was shown by Green (1838) that the wave amplitude is proportional to $D^{-1/4}$. Thus the wave steepens and eventually breaks.

The position of wave breaking is important to the body surfer. Of course, the surfer doesn’t use mathematics to determine where to catch a wave, but merely swims out to the observable position where the waves are consistently breaking. Mathematically, this position can also be determined by stipulating a limiting value on the steepness of the wave front for a train of periodic waves. However, studies have now indicated that it is better to consider each wave crest as an independent entity like a solitary or cnoidal wave rather than as part of a periodic wave train. Grimshaw (1979) has provided a theoretical framework for a more general study of these waves.

Surf Zone

Now that the wave is about to break, the region of most relevance to the body surfer has arrived. Part, or all, of the front of the wave becomes almost vertical and the crest begins to overturn.

If the crest merely overturns down the wave face, the wave is of the spilling or rolling variety and is ideal for gentle body surfing, unless the wave is extremely large. This type of wave tends to occur when the bottom slope is gradual or when the wave breaks in deeper water or breaks in front of an onshore wind.

Some crests overturn completely onto the water surface ahead of the wave, particularly when the bottom slope changes abruptly. This type of breaking wave is termed a dumper or plunging wave. The crest acts like a large jet of water. This jet is also present in the spilling waves, but is not so pronounced.

When the jet plunging progresses laterally across the wave face it gives rise to “barrels” for the plunging wave type and “corners” for the spilling wave type.

An interesting feature of waves about to break is the relatively large force exerted inside the wave, but below the crest, which can propel a body surfer through and out the front of the wave. This method of catching a wave is termed "porpoising" because it is clearly used by dolphins and porpoises to play in the waves near the shoreline just before the waves break. Such forces could be harnessed for their energy in the future, and would be an interesting area of research. Although tidal power has been utilised, direct wave power has not been employed to the same extent, yet waves have been known to move massive rocks and concrete breakwater blocks considerable distances.

When the wave breaks, the surf zone commences. Experiments on the surf zone have been performed by many investigators in laboratory tanks or flumes. Many of these have been reported by Cokelet (1977). Field measurements are fewer, because of the difficulties of maintaining measuring instruments within the boisterous surf zone.

Different measurements would be needed if the main focus of the research in the surf zone was sand transport. However, the emphasis in this research will be on the ability to ride the surf towards the shore or move out through the surf in order to catch a wave.

Once the wave breaks, it travels toward the shore as a turbulent front of foam, bubbles and drops of water. This turbulent breaker can propel body surfers towards the shore. There is a need to investigate the critical lower limit size of a breaker below which a human can no longer be propelled shorewards. This will entail measurements of the water particle mean velocity in the breaker, the length and depth of this forward moving breaker, and the forces that are generated within it to allow a body surfer to ride within it.

Theoretical considerations of the turbulent surf front or breaker have been reviewed by Battjes (1988). Some waves roll right into the beach, while others diminish in an inshore channel and re-form as a smooth surface wave with reduced profile. After the initial jet plunges and causes secondary splashes and disturbance of the water just ahead of the breaking point, laboratory experiments appear to indicate a rapid decrease in height and energy of the breaker. Most breaking waves then seem to settle into a quasi-steady state.

This quasi-steady state consists of a travelling wave form which changes relatively slowly and has a strong turbulent region at the front of the wave reminiscent of a bore. A model of this flow on a beach has been developed by Svendsen and Madsen (1984).

Studies on the quasi-steady breaking waves have been reported by Peregrine and Svendsen (1978). They studied the motion and surface configuration of breakers, bores and hydraulic jumps in flumes. For small-scale jumps they observed that the turbulent region behind a hydraulic jump was quite extensive and wedge-shaped in a vertical plane bounded by the water surface at the top and not quite reaching the bottom of the flume. They hypothesised that the turbulence arose from mixing-layer theory, and that the stationary surface roller did not play a dominant role in the dynamics of the wave. For flow in a breaking wave in the ocean, they hypothesised that the flow is partly a mixing-layer phenomenon and partly a turbulent wake. However, no measurements were able to be made to support these ideas.

Svendsen, Madsen and Buhr Hansen (1978) divided the surf zone into three regions, an outer region just after breaking occurs where there are rapid transitions of wave shape; an inner (or middle) region where rather slow changes in wave shape occur and the wave front resembles a travelling periodic bore; and a final run-up region containing no surface roller (or bore) at all (Figure 2). Their experiments were also conducted in a flume in the laboratory.

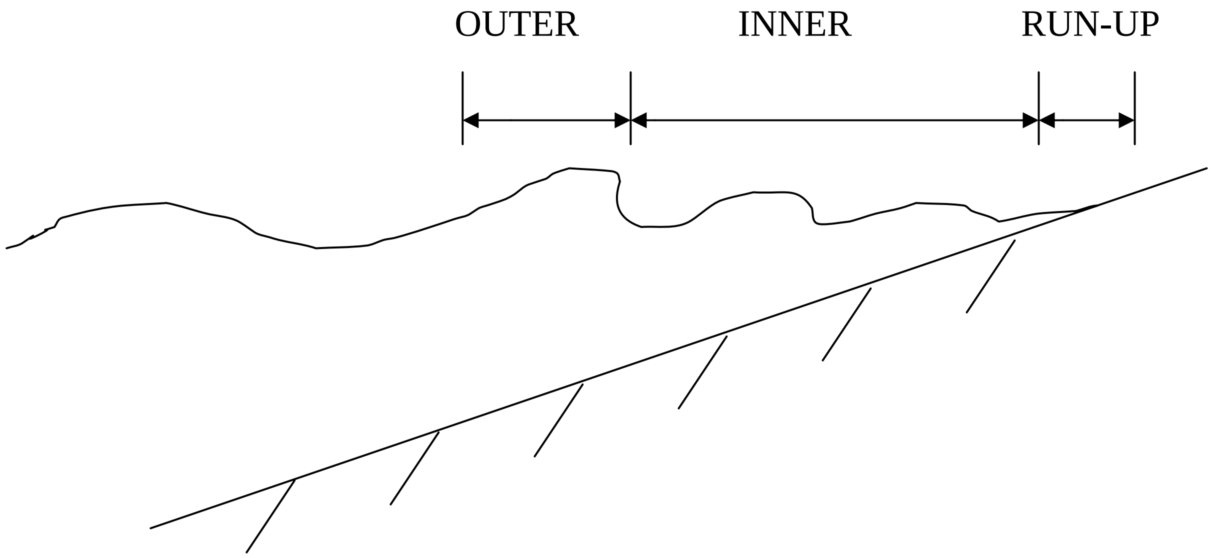

Figure 2. Regions of the Surf Zone.

The inner region is characterised by an almost constant wave front height to water depth ratio. They noted the interesting feature of the inner region that it seems independent of whether the initial breaking wave is of the spilling or plunging type. They then used the Peregrine-Svendsen turbulent mixing-layer model to derive wave characteristics within the surf zone such as velocity of propagation, energy flux, wave height variation and energy dissipation. Again, these have not been confirmed by field experiments.

Other aspects of the surf zone such as tide changes or rip currents can cause the breaking point to move shorewards or seawards. These will not be discussed in this paper.

Field experiments in a Japanese surf zone were conducted by Hotta and Mizuguchi (1980). Using 40 poles placed from the swash (or run-up) region to beyond the surf break and eleven 16mm motion cameras fixed in direction to cover the whole region in overlapping sections, they determined statistics on the maximum height (crest), minimum height (trough) and mean height of the water level as waves passed each pole. Their experiments verified that the waves increase in height towards the breaking point and become more asymmetrical as this point is approached. The wave front approaches the vertical and then breaks. After breaking, the bore-like waves regain some symmetry accompanied by a rapid decay in height. In the experiments the waves recovered their ordinary profile with no foam or turbulence (re-formed waves) because the depth increased again in a small channel parallel to the shore between 20m and 40m from the shore (Figure 3).

Their experiments seemed to indicate that the ratio of wave height to water depth obeyed a linear relationship just seaward of the breaking point. This has implications for surfers watching the oncoming waves for it enables them to choose a suitable one to catch and more easily position themselves for take-off just at the breaking point.

Suhayda and Pettigrew (1977) conducted field experiments on a natural beach in the West Indies with small plunging breakers. They used vertical marker poles but followed each individual wave with the camera right through the region from breaking to run-up. The elevation of the crest (h_c) and trough (h_t) were obtained at each pole, and consequently the wave height H= $h_c - h_t$ could be determined for the turbulent broken surf.

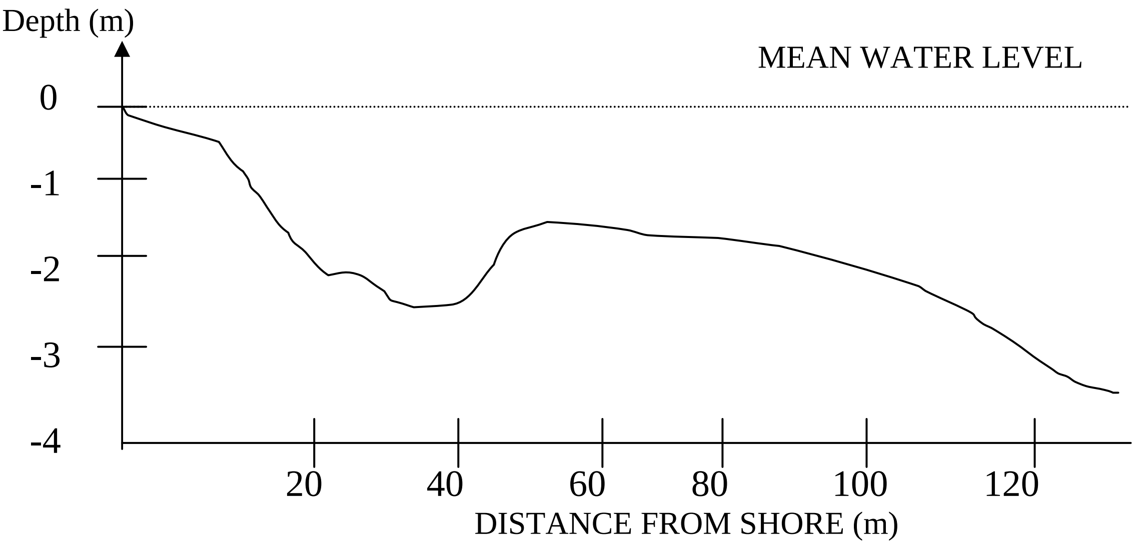

Figure 3. Bottom profile for Hotta and Mizuguchi field experiments (1980).

Comparing their results with theoretical models, they concluded that surf does not behave like a solitary wave nor does it behave like any bore, even a turbulent one.

Good agreement was obtained with the results given by Horikawa and Kuo (1966) who indicated a systematic variation of wave height across the surf zone depending on mutual wave steepness, bottom slope and a turbulent dissipation function. Figure 4 shows the ratio of wave height in the surf zone to maximum wave height at break point (H/H_{max}) as a power-law function of the ratio of trough depth in the surf zone to trough depth at break point (h_t/h_{tmax}), when the slope is 1/30. Good agreement was obtained even though the beach was not of constant slope, but 1/30 was the calculated average slope over the surf zone.

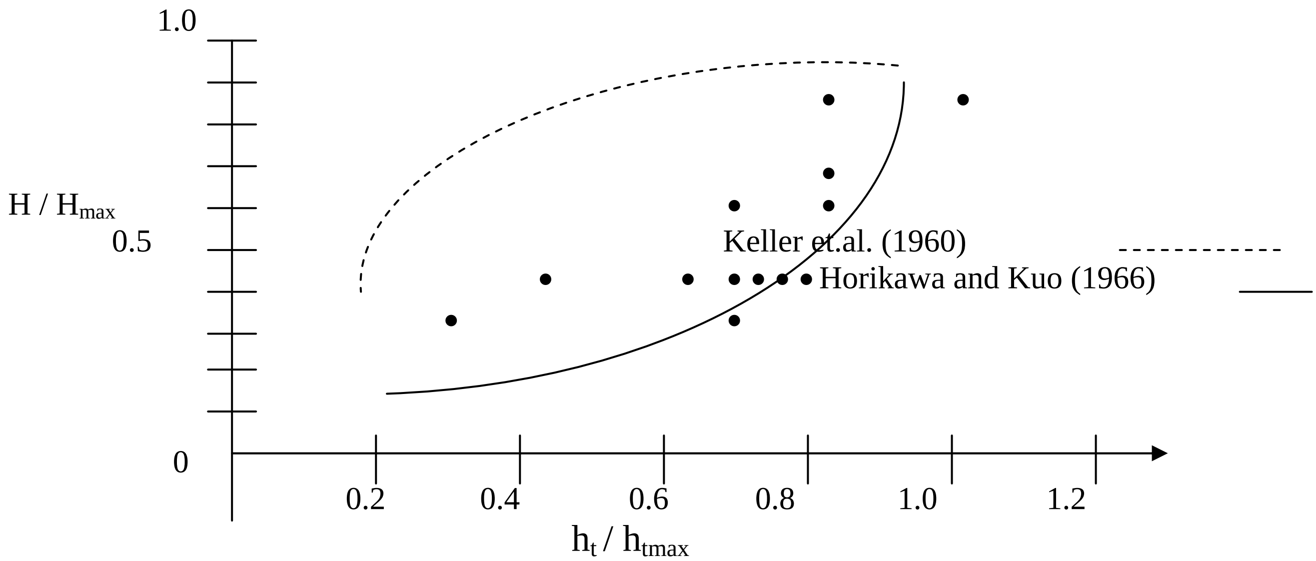

Figure 4. Comparison of field experiments by Suhayda and Pettigrew with theories.

The experimental results were also compared with the turbulent dissipation model of Sawaragi and Iwata (1974) who gave theoretical results for H/H_{max} as a function of X/VT in the surf zone, where X is the shoreward distance from the break point, T is the wave period and V is the wave speed (Figure 5).

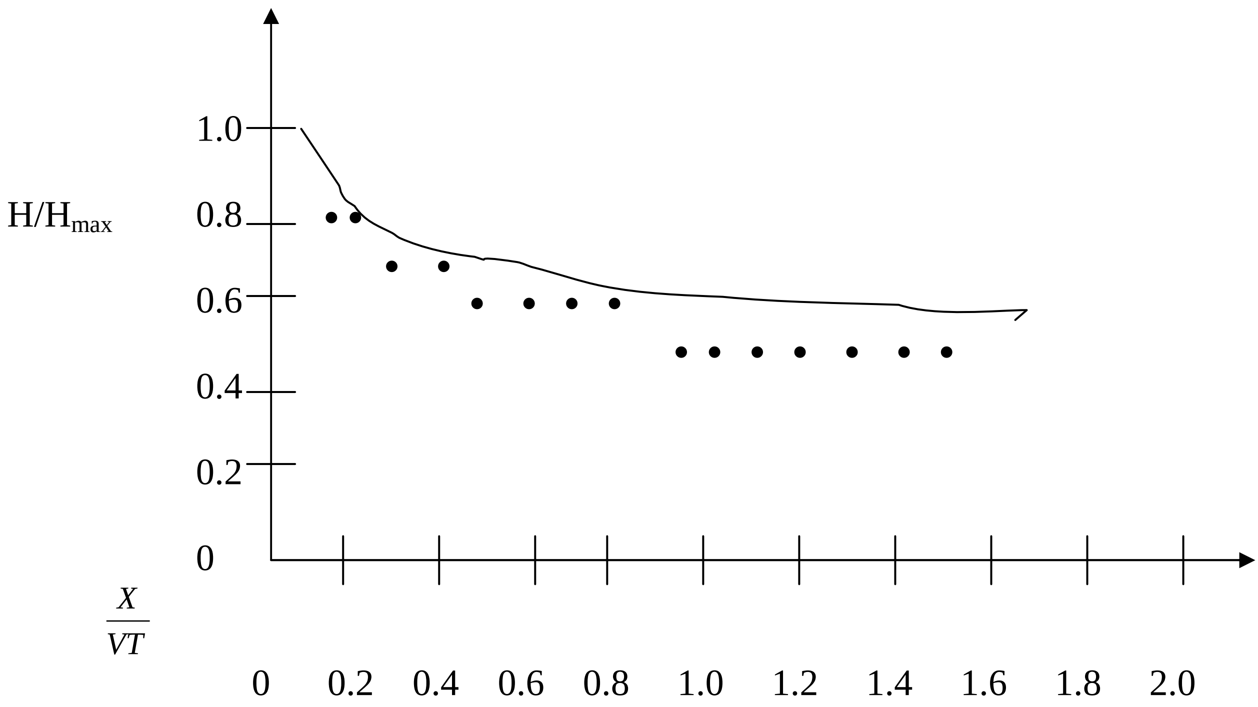

Figure 5. Experiments by Suhayda and Pettigrew (1977) versus turbulence intensity theory of Sawaragi and Iwata (1974) for wave height decay.

Observations in the Surf Zone

Observations that I have made in the surf zone confirm that the surf is not a turbulent bore with turbulence spreading back in a wedge-shaped fashion. Firstly, as the plunging or spilling wave breaks and travels shorewards, the turbulence generated travels shorewards, also in a small region near the wave front. For plunging waves, this can be easily observed right at the breaking point. The wave curls over, causing much turbulence in a short region, but the rear end of this region travels shorewards away from the breaking point as the wave passes. It also begins to dissipate into a less turbulent motion the further it is behind the surf front.

Surfers use the knowledge of this phenomenon to dive under a breaking wave as it passes. The turbulence passes overhead when a surfer dives to the bottom and clings to the sand. The wave just behind the crest surges over the top of his or her body and then diminishes in force as the next trough approaches. Further to this, surfers swimming out through the surf zone in water over waist depth know that to dive under the surf front and cling to the bottom causes them to encounter the least resistance within each wave. There is therefore no evidence of turbulence in a wedge-shaped region extending backwards from the surf front as in laboratory experiments involving stationary bores (hydraulic jumps).

The surf front consists of many secondary waves breaking at the front in small plunging wavelets or jets which create bubbles of air, splashes of waters, reflected jets and foam. However, the length of this turbulent region behind the front has never been measured and along the surface it appears to be about twice the surf wave height.

Catching a Wave

A good swimmer can sprint for a short time at approximately $2ms^{-1}$, whereas the speed of an average wave is about $3ms^{-1}$. It is clear that, for body surfers to catch and ride a wave, they must be able to accelerate quickly to the wave speed. This is easily done in shallow water up to waist depth by standing and propelling the body forward just as the wave touches the back of the legs. The next step is to learn to swim onto a wave and catch it just before it breaks, and some surfers can position themselves so that they only need one swimming stroke to do this.

A mathematical and quantitative examination of this skill is worth while. For a person swimming along a horizontal still water surface, the forces acting in the vertical direction are gravity and buoyancy cancelling each other. In the horizontal direction the forces are the propulsive forward force due to the swimming technique exerted by the swimmer and a quadratic drag force opposing this because the Reynold's number is high enough. The equation governing this is

$$m \ddot{x} = P - k \dot{x}^2 \tag{5}$$

where m is the mass of the swimmer, P is the forward propulsive force, and the resistance coefficient is

$$k = \frac{1}{2} \rho A C_D \tag{6}$$

where ρ is the density of sea-water, A is the area of cross-section of the swimmer normal to the direction of motion, and C_D is the drag coefficient. Note that at the maximum speed $\ddot{x}$ = 0 and so $\dot{x} = \sqrt{P/k}$, indicating that swimmers can only improve their maximum speed by increasing P, decreasing A or decreasing C_D by various techniques.

Consider now a wave traveling with speed U towards a swimmer, who starts swimming in the same direction as the wave is traveling, and reaches maximum speed $\sqrt{P/k}$ at the toe of the wave front just before it is about to break. Timing is important in catching a wave in deep water by swimming "onto it". This is because the force generated within the crest of the wave is usually too small ahead of and behind the break point. There is only "a small window of opportunity" available to use this generated force to build up a swimmer's speed from $\sqrt{P/k}$ to U. It seems reasonable to model this generated force within the wave by $F_\circ$ sin Wx, where $F_\circ$ is maximum force exerted near the crest, and W is a parameter related to the increase in the wave-generated force as each wave front passes a fixed point. Hence, the equation determining the speed gain by the swimmer as the wave passes is

$$m\ddot{x} = F_{\circ} \sin Wx + P - k\dot{x}^2 \qquad (7)$$

This is linear in the dependent variable $\dot{x}^2$ with x as the independent variable and has the initial condition $\dot{x} = \sqrt{P/k}$ when x = 0 (the toe of the wave front). The solution is

$$\dot{x}^2 = \frac{P}{k} + \frac{2F_{\circ}}{(4k^2 + m^2W^2)} \left\{2k \sin Wx - mW \cos Wx + mW \exp(-2kx/m)\right\} \qquad (8)$$

The second term in equation (8) is the gain in speed squared and will determine whether or not the wave speed U is attained. It clearly depends on the strength $F_{\circ}$ of the wave-generated force. Typical values for a swimmer would be m = 75 (kg), k = 15 (kg m^{-1}). Typical values for a wave would be U = 3(ms^{-1}), W = 1(m^{-1}). The horizontal distance from the toe to the crest would be 1.5m. These values simplify equation (8) to

$$\dot{x}^2 = \frac{P}{k} + 0.05\,F_{\circ}$$

For a swimmer whose normal speed is 1ms^{-1}, P/k = 1 and $F_{\circ}$ would have to reach 160 Newtons before the swimmer's speed was accelerated by the wave to 3ms^{-1}. For a swimmer whose normal speed is 2ms^{-1}, P/k = 4 and $F_{\circ}$ would only have to reach 100 Newtons to enable the swimmer's speed to reach 3ms^{-1}. Hence it is easier for the faster swimmer to catch the wave.

Body Surfing

Various body surfing actions are possible, but others are practically impossible.

If an inert floating object such as a log moves into the surf zone from the seaward side, it is pushed shorewards and rolled by the surf front in a transverse orientation. Even logs that are deliberately launched in a longitudinal orientation of minimum drag will align themselves in the transverse mode in a short while. That is, the longitudinal mode is unstable for an inert floating object.

On the other hand, it is impossible for a body surfer to ride a wave in a transverse mode for any appreciable distance. Strangely, it is almost impossible for a body surfer to ride a wave in the longitudinal mode with his or her feet first, and certainly not for any distance. This may be due to the difficulty of launching oneself onto a wave in this position. The preferred orientation for body surfing is in a longitudinal mode, head first and front down. Experienced surfers can also ride a wave for some distance on their back and head first. Strangely, it is almost impossible for a body surfer to ride a wave in the longitudinal mode with his or her feet first and certainly not for any distance.

There are two arm positions for longitudinal body surfing. Many prefer their arms by the side with their head up and protruding ahead of the surf front. Others can obtain a longer ride by having their arms pointed ahead of the shoulders in a diving configuration. The face is then down in the water, and the surfer can breathe now and then by stroking with one arm and turning the head once as in the Australian crawl. On spilling waves, experienced surfers can use their hands in front to "hydroplane" down the wave front as it gently breaks.

One of the best thrills in body surfing is to take advantage of the fact that some waves do not break uniformly everywhere along the front at the same time. For spilling waves this results in "corners" of surf on the front with white water turbulence on one side of the body surfer and "green" unbroken swell on the other side. For plunging waves the result is a surf-tube or barrel where the surfer is riding sideways the curling jet face at the base while the crest section plunges into the surf zone just ahead of him or her. These "tube" or "barrel" rides score highly in board riding competitions, but they are relatively difficult to achieve for a body surfer because of the speed needed to keep up with the breaking tube.

The technique used to ride a tube is useful in coping with waves that dump. Surfers who inadvertently catch a dumper can exit these dangerous waves by sliding sidewards across the face inside the enclosing tube. This enables them to exit out the back of the wave, just like dolphins do. They then escape the possibility of serious neck, head or spinal injury caused by going straight down head first towards the beach to the shallow sand bank below the dumping wave.

When riding broken surf, it is advantageous to kick near the end of the ride to stay on the wave a little longer. Observations indicate that a body surfer on the surf front may only have a small fraction of his body in the turbulent surf front when near the end of the ride shorewards. This is because a large part of the original wave is still moving forwards just behind the turbulent front. When the energy in this main body of the wave dissipates near the run-up or swash region, the feet of the body surfer start to drag and the surfer is dropped by the wave. This can be delayed by kicking the legs, but can also be delayed by surfing with the hands ahead of the body to make it more streamlined.

Other tricks during body surfing include "cork-screwing" down the face of the wave as it is about to break, but this is a difficult manoeuvre on the broken surf front itself. Also, "piggy-backing" or "doubling" on a wave can be performed by two surfers, but the one on the bottom of the two-person pile needs to be able to hold his or her breath for a considerable time. It is also difficult to launch a "piggy-back" attempt from deep water.

Experiments

Experiments have been conducted initially with dowel rods, blocks of wood, S.L.S.A. standard rescue tubes of foam, stiff humans and flexible humans. The dowels and small blocks turned broadside to the surf front as in two-dimensional irrotational theory of flow in a moving stream (Lamb, 1932). The rescue tube (length 1m) with a tail (0.5m) of rope and sash always came in longitudinally. However, the rescue tube without a tail came in transversely, rolling over and over.

Preliminary experiments with a body surfer were conducted at the Gold Coast and show some of the features mentioned above. Videos have been made of surfing a broken wave and a wave about to break. It was found difficult to observe the body surfer in the boisterous surf front. Consequently, a standard SLSA rescue tube was tied around the surfer's waist with little separation between the surfer and the tube. The camera could then easily identify the position of the surfer within the broken wave.

When there is a large separation (2 to 4 metres) between the rescue tube and the body surfer, it has been noted by all surfers that the rescue tube either races ahead of the surfer or drags some distance behind. Both these situations usually cause the body surfer to lose the wave much earlier than if he had no rescue tube attached, because of the extra drag. Attaching it close to the waist reduces this disadvantage.

Other experiments were conducted using small scale body-surfer models (Barbie dolls or long plastic bottles partially filled with sand to obtain almost-neutral buoyancy). These behaved like wooden logs and therefore indicated that there would be no gain in carrying out further experiments at this smaller scale, as the observations would not replicate a body-surfer's behaviour. These models also have no feedback mechanism available, as humans do, to correct the body position during a ride to the shore.

Conclusions So Far

It now appears that when a body surfer "climbs" onto a wave just as it is about to break, he or she is accelerated by the force generated within the wave crest, and picks up speed. When this matches the broken surf front speed of the wave, the surfer is now floating within a moving medium. The wave keeps breaking around the body surfer in small secondary wavelets which push him to the base of the surf front with his head supported by the undisturbed water ahead. The feet of the surfer are usually supported higher than the head and are near the top of the main body of the wave behind the surf front. Hence, the surfer is sloping slightly downwards and moving along within the shorewards-progressing wave.

As the surf front approaches the shoreline, it reaches the undisturbed water level eventually, and then proceeds into the small run-up region. Before this is achieved the legs of the body surfer are no longer in the forward-moving part of the attenuating wave and start to drag. The surfer then goes through the rear of the broken wave front and "falls off it".

The forces on a body surfer are clearly his or her weight balanced by buoyancy in the vertical direction if a full breath has been taken. In the longitudinal direction there are small turbulent buffeting forces, but the mean velocity of the moving surf front carries the surfer along with it until his or her legs start to drag in the slower moving water in the wave trough behind. It may therefore be advantageous to have a short body and legs to travel further. Some surfers have been known to raise one or two lower legs vertically at the knee to ride waves further, and this should also reduce the drag.

Further research needs to investigate:

1. The forces within a nearly-breaking wave.
2. The length of the turbulent region behind the surf front.
3. The minimum height of a surf front for body surfing.
4. The turbulent dissipation behind a surf front.
5. Feet-first body surfing.

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Modelling the Effect of Wind Resistance in the 200-m Sprint

Mike D. Quinn

Sheffield Hallam University, Sheffield, UK S1 1WB

Abstract

A mathematical model is used to simulate the effect of wind conditions on men's and women's 200-m times. Four questions are posed: What is the effect of constant winds on 200-m performance? What is the effect of varying wind speed and direction? What is the effect of the lane allocation? How do wind conditions affect the velocity profile? The race is simulated for winds with constant velocity and direction, for winds from a constant direction where the velocity changes linearly or as a sinusoidal wave, and for winds of constant velocity with a continuously varying direction. Of interest are the different wind conditions which produce tail winds of 2m/s, the maximum allowable for records. Simulations show that prevailing conditions produce large differences in the time corrections. The difference between performances with a wind reading of +2 m/s, but very different conditions, can be 0.8s (men) and 1.0s (women). These are larger than previous estimates and make performance comparisons impossible. Simulations also show that a tail wind blowing directly down the straight exaggerates the difference in lane allocation. The model estimates that on a standard track, a 5m/s tail wind can produce a difference of 0.3s between lanes 1 and 8.

KEYWORDS: AERODYNAMICS, ATHLETICS, MATHEMATICAL MODEL, RUNNING

Introduction

Performances in the 200-m sprint can be significantly affected by wind conditions. Sprinters are assisted by a tail wind when the aerodynamic drag force is reduced. Conversely a head wind increases the drag force, slowing the speed of the sprinter. In the 100-m sprint it has been shown that a 2 m/s tail wind can improve the sprinter's time by around 0.1 s (Linthorne, 1994; Ward-Smith, 1999). In the 200-m the situation is more complicated since more than half of the race is run around a bend. The wind conditions faced by the sprinter will change continuously throughout this part of the race. Moreover, sprinters in each of the eight lanes of a standard running track will experience different conditions. Quinn (2003) has shown that for identical wind readings the athlete can face very different conditions. For an official wind reading of +2 m/s and assuming a constant wind velocity, the time difference can be as much as 0.5 s. The prevailing conditions depend on the wind speed, the wind direction, lane allocation and track specification.

The purpose of this study was to produce an improved mathematical model which accurately simulates the 200-m sprint and use it to analyse the effects of constant and variable winds. The first objective was to develop a model which extends the one used by Quinn (2003). The model should predict the observed velocity profile of world class sprinters and take into account running on a curved path. Four research questions were posed: (1) What is the effect of different constant wind speeds and directions on 200-m performance for both men and women athletes? (2) What is the effect of variable wind speed on 200-m times? (3) What effect does the lane allocation have on 200-m times? (4) How do wind conditions affect the velocity profile?

Methods

The mathematical model used in this study is based on the work of Keller (1973) and the extension made by Quinn (2003). In both studies the assumption of a constant propulsion term lasting throughout the race produced an unrealistic velocity profile. World class sprinters achieve their maximum velocity some distance before the finish (Brűggemann & Glad, 1990; Ferro et al, 2001). In the 100-m sprint the fastest part of the race is between 50m and 60m, while the fastest 50-m segment of the 200-m event is from 50 m to 100 m. To produce the correct velocity profile we have assumed that the propulsive force gradually diminishes throughout the race. The equations of motion for the model are given by:

$$\frac{dv}{dt} = Fe^{-\beta t} - \frac{1}{\tau}v - \alpha(v - v_w)^2 \qquad (1)$$

and

$$v = \frac{ds}{dt} \qquad (2)$$

where *v(t)* is the runner's velocity at time *t*, in the direction of motion, *s(t)* is the distance travelled, $Fe^{-\beta t}$ is the runner's propulsive force per unit mass and $-v/\tau$ is the resistive force. The velocity of the wind relative to the ground and tangent to the path is $v_w(t)$ and

$$\alpha = \frac{\rho C_d A}{2M} \qquad (3)$$

where ρ is the air density, *M* is the mass of the athlete, *A* is the frontal area of the athlete and C_d is the drag coefficient. In this study we take ρ =1.184 kg/m^3, *M* = 74kg (57 kg for women) and *A*= 0.48 m^2 (0.40 m^2 for women) which are the values used by Quinn (2003). The drag coefficient depends on the shape and surface properties of the athlete's body and clothing. As the athlete sprints around the bend there will be some variation in the drag coefficient particularly if the wind conditions are changing too. Wind tunnel experiments using a model and a human in different positions have produced drag coefficient estimates for running ranging from 0.64 to 0.79 (Walpert & Kyle, 1989). In this study we take C_d to be the mean of these values 0.715, and this is also the value used by Ward-Smith & Radford (2002). For a standard running track, as described in Quinn (2003), the length of the straight is 84.4 m while the semi-circular bend is 115.6 m long. This means that in the 200-m event, more than half the race is run around a bend. The sprinter's speed around the bend will be less than the speed achieved when running in a straight line. The sprinter will lean into the bend generating a lateral foot force which balances the centrifugal acceleration (Greene, 1985). This reduces the maximum speed the sprinter can attain on the bend. The reduced speed depends on the sprinter's straight line speed and the radius of curvature of the running lane.

Using Greene's (1985) method, we can correct the velocity for the effect of curvature, which will vary for each lane. This technique has previously been used for correcting the velocity in the 4 ×100-m relay (Ward-Smith & Radford, 2002). The sprinter's speed in a straight line is assumed to be v_0, which is reduced to v when running around a bend with radius of curvature r.

We define the non-dimensional variables

$$\omega = \left(\frac{v}{v_0}\right)^2 \quad \text{and} \quad \lambda = \frac{rg}{{v_0}^2} \tag{4}$$

where g is gravitational acceleration. Greene's (1985) method shows that the relationship between ω and λ is given by the equation

$$\omega = \left(\frac{\lambda^2}{2} + \sqrt{\frac{\lambda^4}{4} + \frac{\lambda^6}{27}}\right)^{1/3} + \left(\frac{\lambda^2}{2} - \sqrt{\frac{\lambda^4}{4} + \frac{\lambda^6}{27}}\right)^{1/3} \tag{5}$$

We can calculate the velocity of the sprinter around the curve by solving equations (1) and (2), and using the correction

$$v = v_0 \sqrt{\omega} \tag{6}$$

This method is used until the sprinter enters the straight.

The value of the wind velocity v_w faced by the sprinter depends on the wind direction and the actual wind velocity u_w. A positive value for v_w corresponds to a tail wind, while a negative value corresponds to a head wind. The wind velocity faced by the sprinter around the curve depends on the distance travelled *s(t)* and the radius of the running lane. On a standard track, the sprinter will enter the straight after a distance of 115.6 m.

If the actual wind speed is $u_w(t)$ blowing at an angle θ to the straight (Figure 1), then around a bend of radius r

$$v_w = u_w \cos(\theta + (115.6 - s)/r) \qquad (0 \le s \le 115.6\,m) \tag{7}$$

and along the straight

$$v_w = u_w \cos\theta \qquad (115.6\,m \le s \le 200\,m) \tag{8}$$

In reality the wind speed will not remain at a constant value throughout the race. There will be some variation in the wind speed and possibly the wind direction during the race. To analyse the effect of such variable winds we simulate for a range of examples where either the wind speed is fluctuating or there is some variation in the wind direction.

We are particularly interested in variable winds which produce an official wind reading of +2 m/s, the maximum tail wind allowed for record purposes. The wind reading is obtained from a single wind gauge which is placed 50 m from the finish and is averaged over a period of 10 s after the first runner enters the straight.

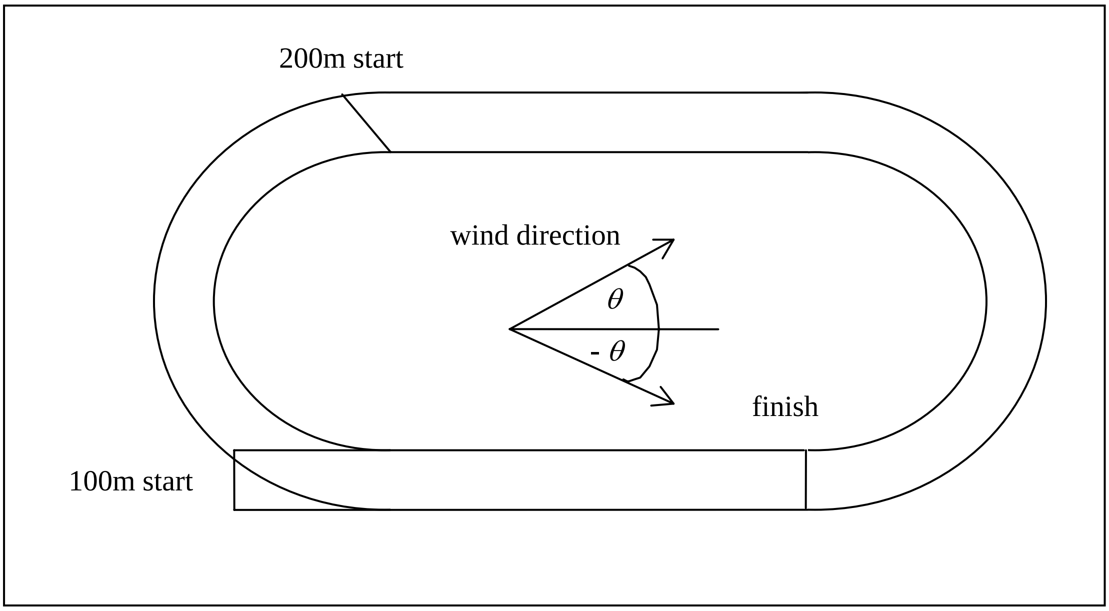

Figure 1. Direction of the wind for the 200-m sprint.

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The first type of a variable wind that we consider has a constant direction and a wind speed which either increases or decreases linearly. The wind velocity is represented by the equation

$$u_w(t) = a_1 t + b_1 \quad (9)$$

An example is a wind blowing directly down the straight ($\theta = 0$) which increases linearly in velocity from 0 m/s to 2.5 m/s during the race and produces a +2 m/s wind reading. A wind from the same direction which decreases linearly in velocity from 4 m/s to 1.5 m/s during the race would also produce a 2 m/s reading. In the simulations we have considered linear winds of this type blowing from the directions $\theta = 0^o, \pm 30^o, \pm 50^o$ and $\pm 70^o$. The following values of a_1 and b_1, which depend on the wind direction, all produce a wind reading of +2 m/s. Notice that the values of a_1 are slightly different for men and women. This is because the wind reading starts only when the sprinter enters the straight and this is approximately 0.9 s slower for women. For increasing winds we take:

$$a_1 = 0.120 \text{ (men)}, a_1 = 0.114 \text{ (women)}, \ b_1 = 0 \ (\theta = 0),$$

$$a_1 = 0.140 \text{ (men)}, a_1 = 0.132 \text{ (women)}, \ b_1 = 0 \ (\theta = 30^o),$$

$$a_1 = 0.188 \text{ (men)}, a_1 = 0.178 \text{ (women)}, \ b_1 = 0 \ (\theta = 50^o),$$

$$a_1 = 0.173 \text{ (men)}, a_1 = 0.163 \text{ (women)}, \ b_1 = 3 \ (\theta = 70^o).$$

For decreasing winds we take:

$a_1 = -0.120$ (men), $a_1 = -0.114$ (women), $b_1 = 4$ $(\theta = 0)$,

$a_1 = -0.102$ (men), $a_1 = -0.097$ (women), $b_1 = 4$ $(\theta = 30^o)$,

$a_1 = -0.110$ (men), $a_1 = -0.108$ (women), $b_1 = 5$ $(\theta = 50^o)$,

$a_1 = -0.130$ (men), $a_1 = -0.123$ (women), $b_1 = 8$ $(\theta = 70^o)$.

The second type of a variable wind that we consider has a constant direction and a sinusoidal wind speed. It is described by either one of the following equations

$$u_w(t) = a_2 \sin(c_2 t) + b_2$$
$$u_w(t) = a_2 \cos(c_3 t) + b_2 \quad (10)$$

An example is a wind blowing directly down the straight (θ = 0) with a sinusoidal velocity varying between 0 m/s and 4 m/s. In the simulations we consider four particular winds with sinusoidal velocity (types (a) to (d)) blowing from the directions $\theta = 0^o, \pm 30^o, \pm 50^o$ and $\pm 70^o$. The following values produce wind readings of +2 m/s:

Type (a) $a_2 = 2$, $c_2 = 0.190$ (men), $c_2 = 0.180$ (women)

Type (b) $a_2 = -2$, $c_2 = 0.190$ (men), $c_2 = 0.180$ (women)

Type (c) $a_2 = 2$, $c_3 = 0.286$ (men), $c_3 = 0.270$ (women)

Type (d) $a_2 = -2$, $c_3 = 0.286$ (men), $c_3 = 0.270$ (women).

The value of b_2 depends on the wind direction

$b_2 = 2$ (θ =0), $b_2 = 2.31$ ($\theta = \pm 30^o$), $b_2 = 3.11$ ($\theta = \pm 50^o$), $b_2 = 5.85$ ($\theta = \pm 70^o$)

The third type of variable wind considered has a constant wind speed but the wind direction changes linearly throughout the race. The variable wind direction θ(t) is given by

$$\theta(t) = \varphi + a_3 t + b_3 \quad (11)$$

In the simulations we take the angle φ to be $0^o, \pm 30^o, \pm 50^o$ and $\pm 70^o$. For example, if $\varphi = 30^o$ the wind direction changes linearly from $\theta = 20^o$ to $\theta = 40^o$ (anticlockwise) or from $\theta = 40^o$ to $\theta = 20^o$ (clockwise), during the 10 s period when the wind reading is taken. For anticlockwise linear winds

$a_3 = 0.035$ (men), $b_3 = -0.525$ (men), $b_3 = -0.595$ (women)

and for clockwise linear winds

$a_3 = -0.035$ (men), $b_3 = 0.525$ (men), $b_3 = 0.595$ (women)

The fourth type of a variable wind that we consider has a constant wind speed but there is a sinusoidal variation in the wind direction. The variable wind direction θ(t) is given by either one of the equations

$$\theta(t) = \varphi + a_4 \sin(c_4 t)$$
$$\theta(t) = \varphi + a_4 \cos(c_5 t) \quad (12)$$

Again in the simulations we take the angle φ to be 0^o, $\pm 30^o$, $\pm 50^o$ and $\pm 70^o$. For example if $\varphi = 50^o$ the sinusoidal wind direction varies between $\theta = 35^o$ and $\theta = 65^o$ during the 10 s period when the wind reading is taken. In the simulations we consider four particular winds with sinusoidal direction, all of which produce a wind reading of +2 m/s. The values which produce these four winds (Types (e) to (h)) are described below:

$$\text{Type (e)}\ a_4 = 0.262,\ c_4 = 0.628$$
$$\text{Type (f)}\ a_4 = -0.262,\ c_4 = 0.628$$
$$\text{Type (g)}\ a_4 = 0.262,\ c_5 = 0.628$$
$$\text{Type (h)}\ a_4 = -0.262,\ c_5 = 0.628$$

The non-linear equations of motion have no analytical solution and were solved numerically using a fourth order Runge-Kutta method. The model parameters F, τ and β were chosen to fit the available 200-m data from the 1999 World Athletics Championships (Ferro et al, 2001).

Results

The model was tested using 100-m data from Ferro et al (2001) and produced an accurate simulation matching the recognised velocity profile. The estimated times for constant winds ranging from -5 m/s to +5 m/s agreed with the results of Linthorne (1994).
The model parameters were then chosen to fit the 200-m data for both men and women (Ferro et al, 2001). The athlete was assumed to be running in lane 4 of a track with standard dimensions in windless conditions. The model produced an excellent fit to the data giving the appropriate velocity profile. The second 50-m section was the fastest part of the race with the maximum speed attained between 50 m and 60 m (Table 1).

Table 1.200-m Simulation for World Class Sprinters

	Men		*Women*	
Distance m	*time s*	*velocity m/s*	*time s*	*velocity m/s*
50	5.68	11.26	6.04	10.40
100	10.17	10.89	10.95	9.92
150	14.84	10.57	16.12	9.41
200	19.72	9.88	21.65	8.66
Finish time	*19.86*		*21.79*	

Note: A reaction time of 0.14 s is assumed.

The model was used to simulate the effect of winds of constant velocity from -5 m/s to +5 m/s, blowing directly down the straight ($\theta = 0$). The time correction ranged from +0.50 s (men), +0.65 s (women) for a 5 m/s head wind to -0.23 s (men), -0.27 s (women) for a 5 m/s tail wind (Table 2).

Table 2.Correction Estimates (s) for Winds of Constant Velocity

θ=0	*Lane 1*		*Lane 8*		*Average of 8 Lanes*	
v_w *m/s*	men	women	men	women	men	women
-5	+0.46	+0.60	+0.55	+0.70	+0.50	+0.65
-4	+0.35	+0.45	+0.41	+0.53	+0.38	+0.49
-3	+0.24	+0.31	+0.30	+0.37	+0.27	+0.34
-2	+0.15	+0.19	+0.18	+0.24	+0.17	+0.22
-1	+0.06	+0.09	+0.09	+0.11	+0.08	+0.10
1	-0.06	-0.07	-0.07	-0.09	-0.07	-0.08
2	-0.10	-0.13	-0.15	-0.17	-0.13	-0.15
3	-0.14	-0.17	-0.19	-0.24	-0.16	-0.21
4	-0.17	-0.19	-0.25	-0.30	-0.21	-0.25
5	-0.18	-0.20	-0.28	-0.34	-0.23	-0.27

Note: The wind direction is assumed to be along the straight (θ =0)

The next set of simulations compared performances when the official wind speed reading was +2 m/s. Winds of constant velocity and fixed direction ranging from $\theta = -70^o$ to $\theta = +70^o$ produced a wide range of times, even though the official wind readings were identical (Figure 2).

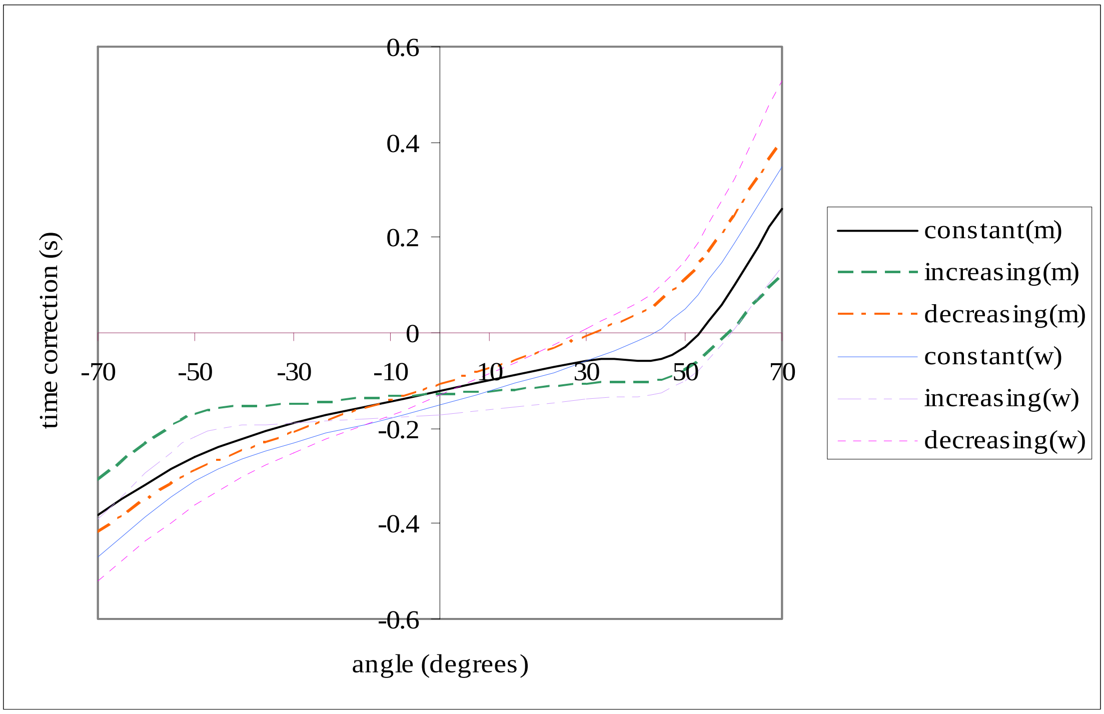

Figure 2. Time corrections (s) for men (m) and women (w) for winds blowing from different directions (θ^o) where the wind velocity is either constant, increasing linearly or decreasing linearly.

Time corrections for winds where the velocity decreased linearly produced an even larger variation (Figure 2). For men the performances varied from 19.30 s to 20.12 s, a time correction difference of 0.82 s. The range was even larger for women where the performances varied from 21.13 s to 22.18 s, a range of 1.05 s.

Winds where the velocity varied in a sinusoidal way also produced large variations in the time corrections (Figure 3).

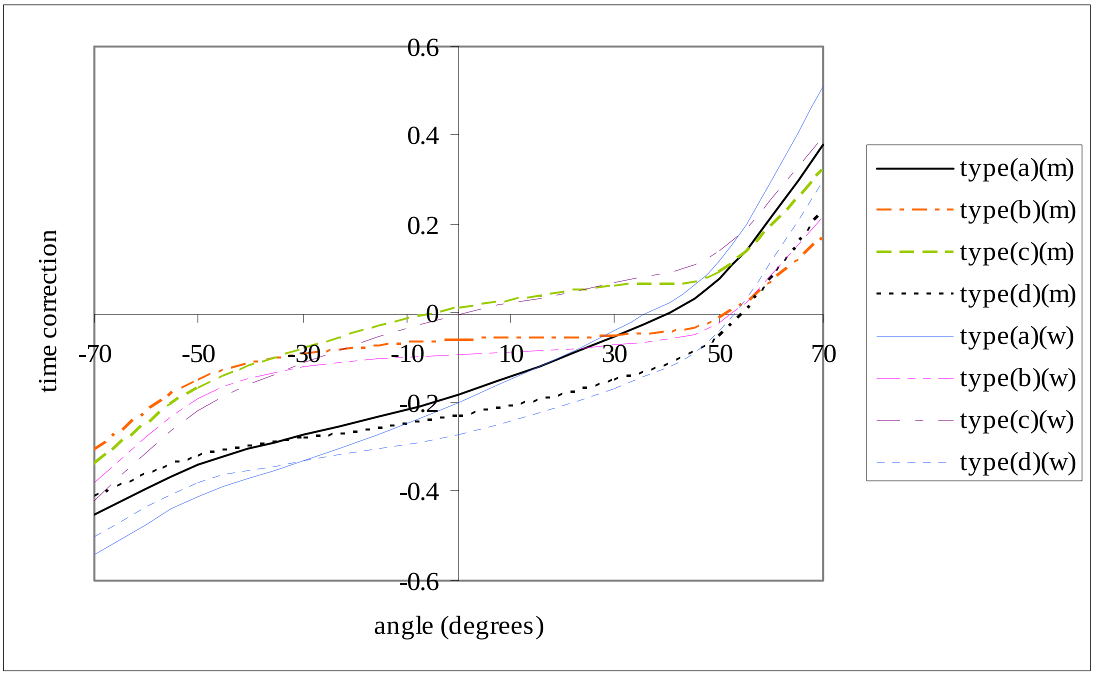

Figure 3. Time corrections (s) for winds blowing from different directions (θ°) where the wind velocity is sinusoidal.

Further simulations indicate that winds of constant velocity but with a varying direction also produce large variations in the time corrections. A wind of constant velocity with the direction varying linearly can produce a time correction difference of 0.65 s (men) and 0.78 s (women) (Figure 4). This range is further amplified when the wind direction varies in a sinusoidal way (Figure 5).

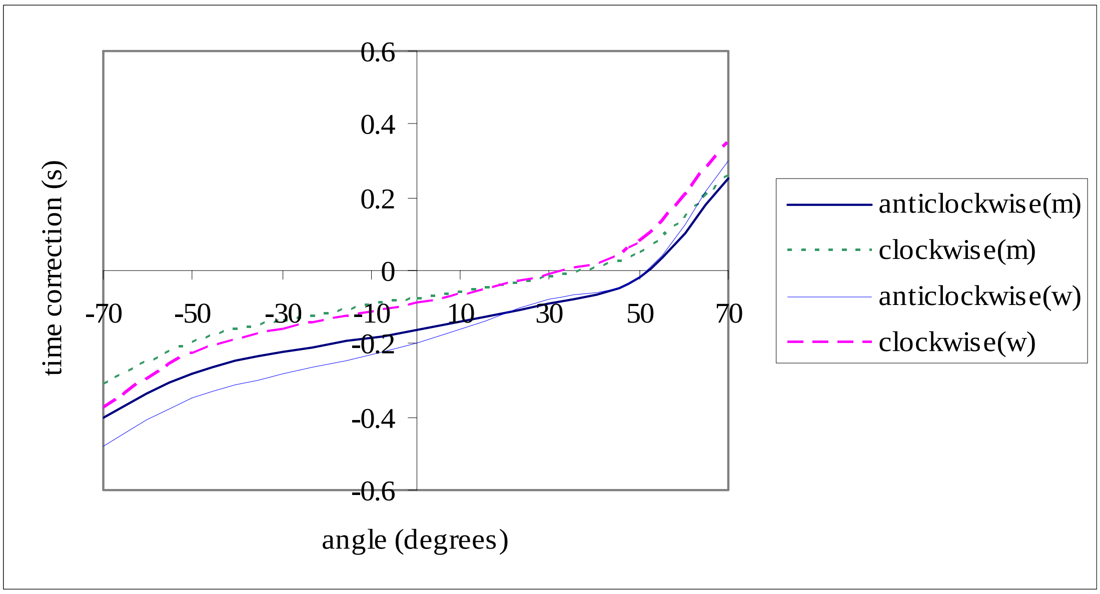

Figure 4. Time corrections (s) for winds of constant velocity where the variation in wind direction is linear.

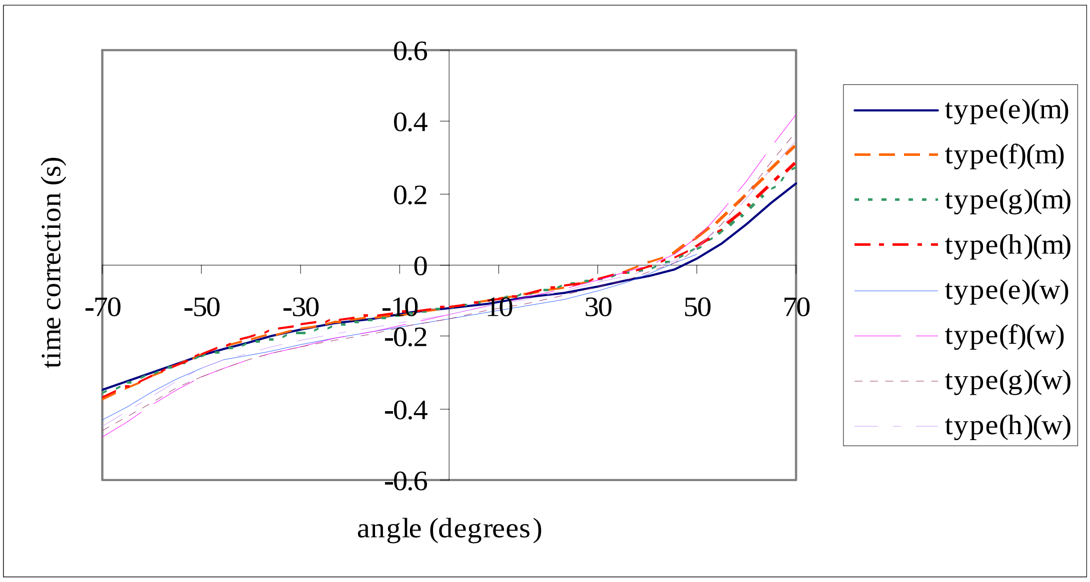

Figure 5. Time corrections (s) for winds of constant velocity where the variation in wind direction is sinusoidal.

Note: In Figures 2, 3, 4 and 5 an average of 8 lanes is taken and all winds produce a +2 m/s reading.

The model was also used to estimate the effect of lane allocation under different wind conditions. In windless conditions a male runner in lane 8 has a 0.20 s advantage over the lane 1 runner. The time differential between the lanes changes for different winds of constant velocity blowing directly down the straight (θ = 0). For a head wind of -5 m/s the time correction range between lanes 1 and 8 was reduced to 0.11 s (men). For tail winds the time difference between the lanes increased (Figure 6).

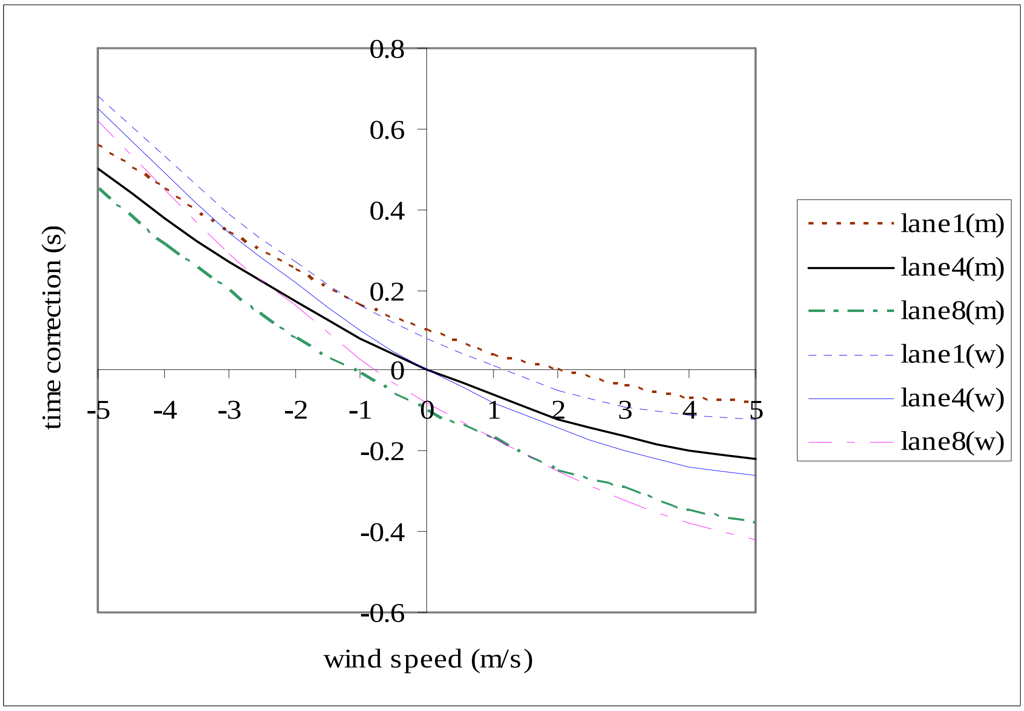

Figure 6. Time corrections (s) in lanes 1, 4 and 8 for winds of constant velocity (θ = 0).

Discussion

The simulation in Quinn (2003) provided a useful insight into the effects of wind in the 200-m sprint. The mathematical model used in this study improves on this work by accurately predicting the velocity profile and taking into account running around the bend. The model is not as sophisticated as the energy conversion model of Ward-Smith (1999). However this lack of complexity makes it more suitable for simulating the complicated nature of the 200-m event, particularly when analysing the effect of varying wind speed.

The results for constant winds generally confirmed the conclusions of Quinn (2003) although there were some minor differences. Time corrections for tail winds blowing along the direction of the straight agreed, but head winds produced larger time corrections (Table 2). For crosswinds the time corrections were considerably larger than described in Quinn (2003) (Figure 2). This difference is likely to be due to the more realistic velocity profile and treatment of bend running in the current model.

The results indicate that winds of variable velocity can exaggerate the difference in time corrections for performances with identical wind readings. For winds where the velocity is either decreasing linearly or sinusoidal (type a) blowing at an angle to the straight, the official tail wind reading of 2 m/s can be misleading. If the angle to the straight is $\theta = 70^o$ the wind can actually cost the runner up to 0.40 s (men) and 0.53 s (women). The simulations show that for a reading of +2 m/s, the time difference averaged over eight lanes can be as large as 0.83 s for men and 1.05 s for women (Figure 3). This suggests that the figure of 0.5 s given by Quinn (2003) when modelling only constant winds underestimates the true situation.

To put this into context it means that a performance by a male sprinter of 19.27 s would be slowed to a time of 20.10 s by adverse wind conditions even though both have the identical wind reading of +2.0 m/s. For women, a time of 22.18 s (wind reading +2.0 m/s) could well be equivalent to a performance of 21.13 s with the same wind reading. This highlights the unsatisfactory situation at present concerning 200-m race wind readings.

The effect of lane allocation was extremely marked under certain wind conditions. From a biomechanical viewpoint, lane 8 (the outside lane) is the fastest. However the middle lanes 3 to 6 are favoured by most athletes and are used for the top seeded runners in championship races. There are clearly psychological aspects involved which include the fact that most competitors prefer to have some target runners on their outside. In windless conditions the difference between the extreme lanes was 0.20s (men) and 0.16 s (women). A tail wind blowing directly down the straight increased the lane differential (0.30 s for men and women with a 5 m/s wind) since the runners in the outside lanes experience less of a headwind in the early part of the race. In contrast a head wind in the straight ($\theta = 0$) reduced the lane effect. A -5 m/s head wind produced a time differential between lanes 1 and 8 of only 0.11 s (men) and 0.06 s (women). Figure 6 illustrates this effect for lanes 1, 4 and 8.

The wind speed also altered the velocity profile of the sprinter. For tail winds along the direction of the straight the maximum velocity was attained later (between 60 m and 75 m for v_w= 4 m/s). In the early part of the race the sprinter would experience a head wind, causing a delay in reaching the top speed. A head wind in the straight has the opposite effect, causing the sprinter to attain maximum velocity earlier (between 45 m to 50 m for v_w= -4 m/s).

The simulations show that the variation in 200-m times which have the same official wind readings is much greater then previously thought. Simulations using winds with variable speed and direction show a greater variation than the estimates using constant winds. Clearly without further information about the prevailing weather conditions it is virtually impossible to compare performances in the 200-m. Currently the information on wind conditions is totally inadequate since it consists of a reading from a single wind gauge placed in the straight and there is no data on conditions around the curve. Instead a series of wind gauges is required, placed on both sides of the track along the length of the 200-m.

Further developments of the mathematical model could include a variation in the drag coefficient as the sprinter runs the bend. However, this would require more empirical data from wind tunnel experiments.

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A Neural Network approach to pattern learning in sport

Jürgen Perl, Kathrin Weber
Institute of Computer Science, FB 17
University of Mainz
D-55099 Mainz, Germany

KEYWORDS: NEURAL NETWORK, PATTERN LEARNING, SCHEDULING

Introduction: Process analysis by means of Neural Networks

Processes in sport can be described as time series of patterns, which can as well characterize situations (e.g. positions on the playground or angles of articulations) as activities (e.g. moving of players or angle speeds).
Patterns can be learned and recognized by means of "self organizing maps" (SOM) the most famous type of which is that of Kohonen Feature Map (KFM) (see Kohonen (1981), Hopfield (1982), Köhle (1990), Polani & Uthmann (1993)).
Therefore SOMs like KFMs can help to analyse processes in sport, as has been done in several approaches (see Lames & Perl (1999), Schöllhorn & Perl (2002), Schöllhorn et al. (2002), Lippolt et al. (2004)).
However, there is a type of problem that is difficult to handle with a "conventional" KFM – namely if learning itself is the process to be analysed:
Due to the fact that a KFM learning process is controlled by an external algorithm using parameters that run down to final values and so eventually cause the end of the learning process, a once trained KFM cannot be reactivated. Therefore additional or continuing learning can be done only by repetitions of the learning process using appropriate mixtures of data from the different phases of the learning process – which is uncomfortable as well as methodologically not satisfying. In order to handle this problem, the concept of Dynamically Controlled Network (DyCoN) has been developed in our working group.

Modelling learning processes by means of DyCoN

The DyCoN-concept is based on the KFM-concept but is different in the main point of internal organisation: The dynamics of each neurone is based on the Performance Potential Metamodel (PerPot), (see Perl (2002 a) and for more details www.informatik.uni-mainz.de/perpot), which originally was developed in order to model physiologic adaptation processes. This way, every neurone contains an internal memory and a self-controlling algorithm. The effect of the individual neural self-control is that a DyCoN has no final state but always can adapt its internal memory to new input and therefore can learn continuously as well as in separate phases (see Perl (2001), Perl (2002 a), Perl (2002 b)). The idea of the DyCoN-concept is documented in more detail in www.informatik.uni-mainz.de/dycon.
One effect of the dynamic learning ability is that patterns can superpose or complete each other if learned one after the other in a continuous learning process (see Figure 1).

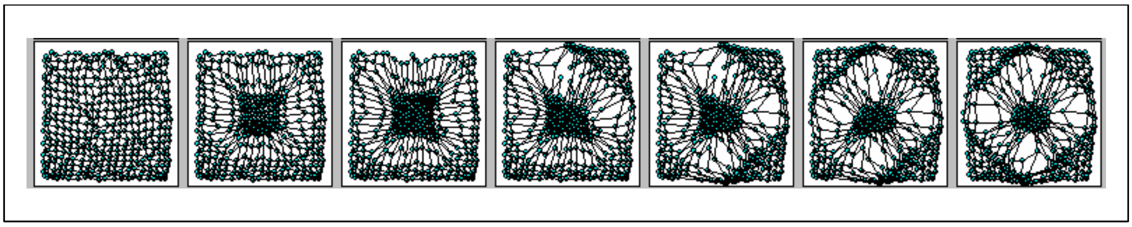

Figure 1. Visualisation of a continuous superposing learning process using geometrical patterns like squares (graphics 1, 2, 3) and triangles (graphics 4, 5, 6, 7)

Moreover, a DyCoN-neurone also can forget its information and so enables to replace one pattern by another one in a replacing learning process (see Figure 2).

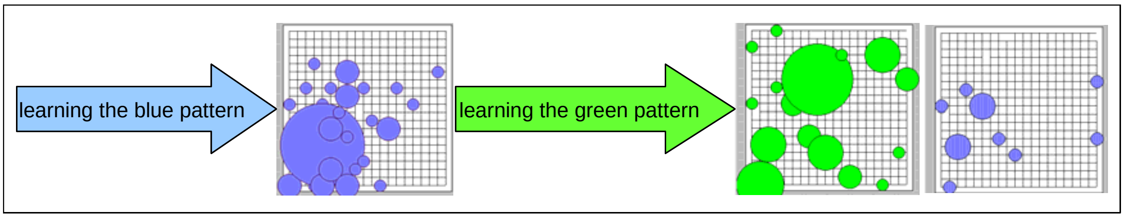

Figure 2. First learning the blue pattern results in a high degree of presence that is represented by the number and the diameters of the blue circles. A following training with the green pattern establishes the green presence and reduces the blue one.

These examples represent a typical conflict situation in learning processes: Sometimes one already learned pattern has to be completed by another one – e.g. if the backhand technique is added to an already available forehand technique – sometimes one already learned pattern has to be replaced by another one – e.g. if a wrong technique has to be improved. Obviously, appropriate learning schedules are necessary to meet the respective intentions. The questions are, whether such schedules can be found and seem to be reasonably transferable to human learning and so could help for optimizing learning and training strategies, e.g. in the areas of motor learning or tactical game analysis.
A first approach has been developed by Weber (2004), where a Genetic Algorithm calculates best fitting learning schedules to given objectives.

Optimisation of learning schedules by means of Genetic Algorithms

The number of possible schedules is enormous, and as long as there is no idea what a successful training profile could be it seems to be hopeless to find an optimal schedule. However, as is well-known from similar problems of this type, Genetic Algorithms (GA) can be helpful due to their ability of selecting, modifying and combining parts of temporary solutions.
In the study of Weber, the GA had to arrange the training of two different patterns, where the one objective was superposing learning in the sense of establishing two patterns with equal degrees of presence, and the other objective was replacing learning. The structure of the schedules was given as an equidistant scheme of time-slots. The GA had to select one of the two patterns as well as the regarding learning intensity for each time-slot.
Briefly spoken, the results are as follows: In the case of superposing learning the optimal schedules are of the types shown in Figure 3, meaning that alternating learning phases with moderate learning intensities fit best for a balanced presence of two patterns.

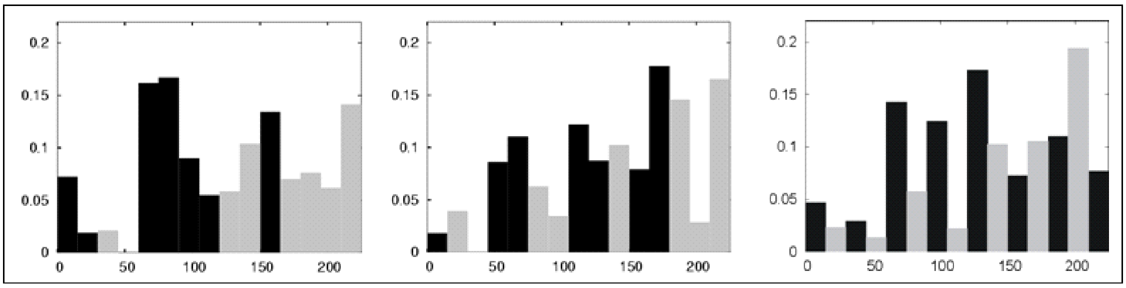

Figure 3. Three characteristic types of optimal schedules in case of superposing learning (black and grey the learning intensities of the respective patterns). In the right graphic the alternating learning rhythm was given, and only the intensities were optimised.

In the case of replacing learning the first result (Figure 4, left graphic) met the expectations: The replacing pattern had to be learned with a rather high sum of intensity. Additional tests however showed that an even better result could be reached by first "attacking" the net with an erasing third pattern (Figure 4, right graphic) – which can be interpreted as "brain washing".

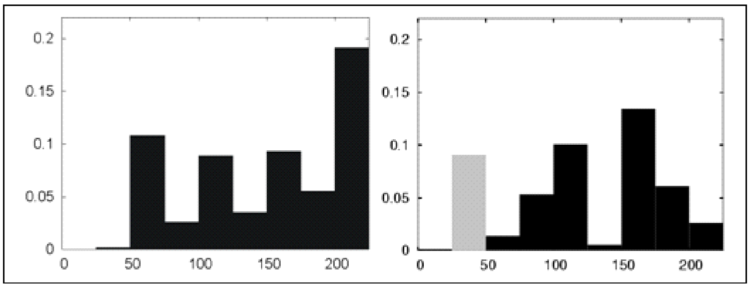

Figure 4. Left graphic: Typical learning schedule in case of replacing learning (black columns: learning intensities of replacing patterns). Right graphic: Learning with additional erasing pattern (grey column).

On the basis of those first ideas what optimal schedule structures could be, more targeted investigation can be done in order to handle more than two patterns or get more information about details of pattern learning. One first example is given in Figure 3, right graphic: If the idea is that optimal schedules are those with equally distributed learning phases, the optimisation process can be reduced to calculating the respective intensities.

It should be emphasized again that "learning" in this study does not mean just a technical externally controlled algorithm but a complex internally controlled dynamics, where each neurone has its own memory and plays its individual role in adapting to a given pattern. In the same way as the underlying PerPot-model of antagonistic physiologic adaptation helps for a better understanding of training-processes the corresponding DyCoN approach might be helpful for a better understanding of the dynamics of learning processes.

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