Yeadon, M.R. 2005. What are the limitations of experimental and theoretical approaches in sports biomechanics? In Philosophy and the Sciences of Exercise, Health and Sport: Critical Perspectives on Research Methods (Ed. M. McNamee), pp. 133-143. London: Routledge. ISBN 0415300169.

Introduction

In these days of the sound byte and the buzz word we often here the phrase "World Class Sports Science Support". This seems to conjure up the notion of "World Class Sports Science" but actually refers to the "Sports Science Support" provided to world class sports competitors. The phrase "Sports Science Support" suggests support that is based on the results of sports science research. There is much to be said for this intention but there are a number of factors that limit the theoretical underpinning of such support in sports biomechanics and other branches of sports science. Firstly, it should be noted that while there are some findings that are applicable to the majority of sports, the most useful results are often sport-specific. For example the requirements for success in gymnastics from the perspectives of biomechanics, physiology, psychology and sociology of gymnastics are all quite different from the corresponding requirements for success in field hockey. This means that in order to provide well informed advice on a particular sport from the perspective of a particular discipline it is necessary to have a body of research for that discipline-sport combination. Secondly, while the amount of sports science research is steadily increasing, the disciplinary study of individual sports is limited both by the large number of sports and by the relatively small number of sports scientists undertaking such research. As a consequence "World Class Sports Science Support" will continue to be support that has a relatively weak foundation of relevant research. This will remain the situation until such time as some agency takes responsibility for the funding of sports science research.

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above description is that of “Experimental Method” rather than “Scientific Method”. In Exercise Physiology, for example, so much of the research is experimentally based that a student might assume that “Science is Experimental Science” but this neglects an important aspect of scientific investigation, namely “Theoretical Sciencs experimental group and a control group and will assess the difference in performance of the two groups using statistical tests. On the other hand Einstein's General Theory of Relativity predicted that the Sun would bend light from a distant star through 1.74 seconds of arc (0.0005^o) rather than half this amount as predfr etro possible to obtain clear results from an experiment with an athlete. For example, Greig and Yeadon (2000) used data on 16 high jumping trials from a training session of one athlete to establish quadratic relationships between approach speed and height jumped and between leg plant angle and height jumped.

Because of the difficulties in obtaining sufficient data on a single athlete, some researchers use combined data from several athletes. Hay (1987) cautions against statistical analyses in which several jumps by each of a number of athletes are treated as if they were single trials performed by different athletes, since trials by the same athlete cannot be regarded as independent trials. A more appropriate approach would be to use a repeated measures design. Additionally it should be recognised that the relationships between variables may be very different when the best performances of a number of athletes are taken rather than a number of performances from a single athlete. The relationship between height reached and approach speed in high jumping is quadratic for an individual (Alexander, 1990) so that there is an optimum approach speed for which the height jumped is greatest. On the other hand, the relationship is linear for a group of athletes (Dapena et al., 1990) so that the height jumped increases with the approach speed. In other words while there is an optimum approach speed for an individual, the better jumpers are stronger, faster and jump higher. Confusion in this area can lead to relationships that are unrelated to individual performance.

Figure 2. A hypothetical data set showing approach speed and distance jumped for long jumping.

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however, all performances are likely to be close to optimum. This results not only in a small range of variable values but also in a flat response. Near an optimum a performance variable such as distance jumped will be quadratically related to a variable such as approach speed so that the theoretical graph will resemble an inverted U (Figure 2). Around the optimum, therefore, data will exhibit a flat linear trend rather than an inclined linear response. As a consequence linear regression analysis will yield no relationship. On the other hand quadratic regression analysis will also yield little due to the small amount and range of data. Failure to recognise such effects will result in abortive attempts to reveal underlying relationships.

Linear regression is sometimes used in a fishing expedition to find relationships between variables by investigating every pair of variables. This "shotgun" approach has the drawback that it may identify "significant" relationships when, in reality, no such relationships exist. For example, if the level of significance is set at 5% and all 45 pairs from 10 variables are regressed in turn, it may be expected that two "significant" regressions will occur by chance. If there are three significant regressions in such a study then it may be that there is a real relationship between a pair of variables but which pair of the three will not be known. Extreme examples of this type report the expected number of random correlations as significant (Williams et al., 1988).

Hay and Reid (1982) proposed a hierarchical deterministic structure for identifying potential causal relationships prior to performing regressions of one variable against another. While this procedure is certainly an improvement upon regressing each variable against all others, implementations include a number of
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the weaknesses described above. Firstly, the deterministic model h ec 7j 5.4 0 Td ( )Tj 4.92 0 Td (a)T

without arm swing. It may be possible to demonstrate experimentally that jumps with arm swing allow greater leg extensor force to occur and that greater jump height occurs. To demonstrate that the leg extensors are in slower concentric conditions as a consequence of the arm swing requires the use of a theoretical model (Dapena, 1999). As a consequence studies aiming to reveal mechanisms using experimental studies of whole body movement either speculate on the mechanisms (Lees et al., 1994) or conclude that the mechanisms are unclear (Feltner et al., 1999).

Interpretation of experimental results is often a function of how the world is viewed. The leap from an experimental result that more training results in better performance to a general conclusion to this effect arises from an (unstated) belief that response is linear when in general it is not. Komi and Mero (1985) express surprise that the increase in javelin range is disproportionately larger that the increase in release velocity. This error arises oo[illegible]sn rate 98[illegible]gm tins e i necessary to identify which elements of the real system should be included and how they should be represented. This is not a straightforward task as there is no guarantee that a carefully constructed model will perform in the required manner. A typical model in sports biomechanics might comprise a number of body segments connected by simple pin joints together with some mechanism for exerting torque about each joint (e.g. Hatze, 1981). Often a process of iteration is necessary in which modifications are made until the model is able to match an actual performance. For example wobbling masses may be included within the model to represent soft tissue movement within the segments (Gruber et al., 1998). Without such wobbling masses the forces calculated by a model may overestimate the actual forces in a movement. In order to assess when modifications result in an adequate model, a quantitative method of model evaluation is required. Typically data obtained from a real performance will be used as input to the model and the model output will be compared with the corresponding values from the actual performance. The cycle of model improvement is shown in Figure 3.

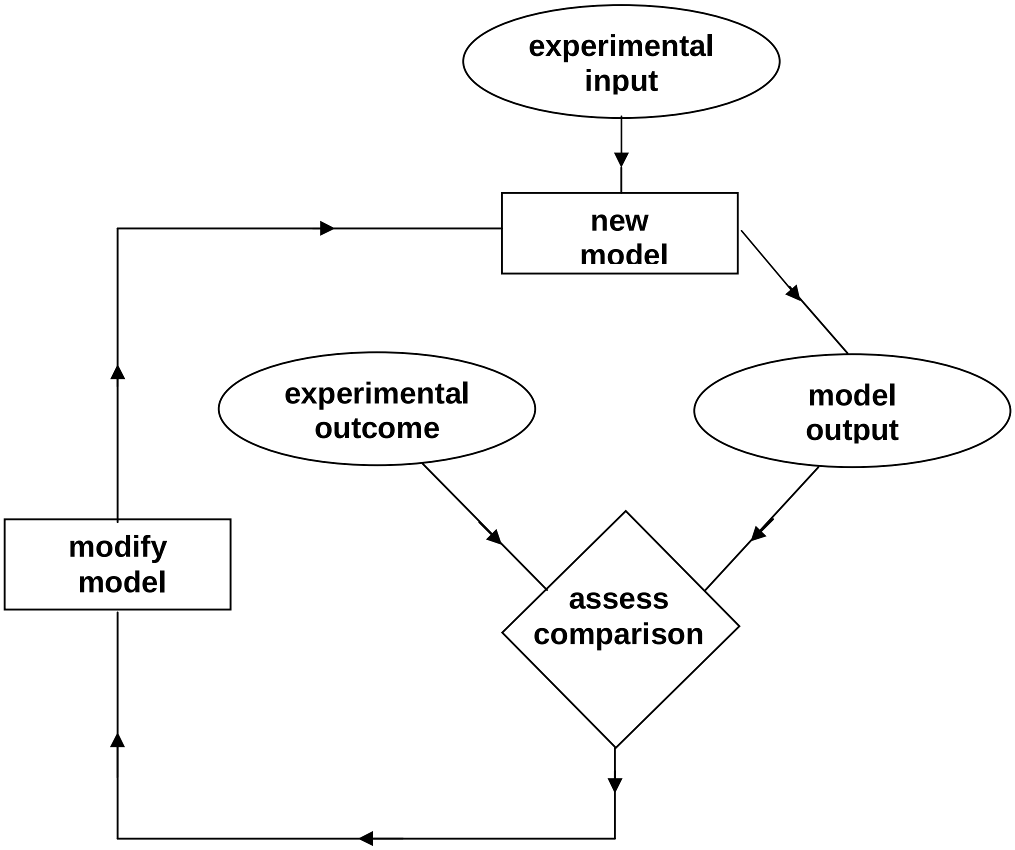

Figure 3. The cycle of model evaluation and model modification.

for optimal technique there are potential problems. Even with sophisticated optimisation programs such as Simulated Annealing (Goffe et al., 1994) there is no guarantee that the global optimum will be found. The search for an optimum can be likened to the search for the highest mountain peak in a given terrain. An optimisation routine may find a local rather than a global optimum. In other words the software may find the top of a foothill rather than the summit of the highest mountain. On the other hand the routine may be successful in finding the top of a singular pinnacle that stands on a narrow base high above the surrounding terrain. Even if this is the global optimum it is a summit that should not be attempted since any small location error will land on low terrain. In other words if there is an optimum technique in javelin that is surrounded by poor performances, it is a poor strategy that strives for this in the distant hope that everything will come right on one of the attempts. The likelihood is that all performances will be poor. A better strategy may be to find a high hilltop with a large plateau so that points even some distance away are high. There is much to be said for consistency when competing.

Attempts to identify an optimisation criterion that is responsible for the adoption of a particular strategy can suffer from a failure to consider the context holistically. If the research focus is lead by information from descriptive studies then little insight may be gained. For example in trying to explain why a smooth movement strategy is adopted for tasks such as drawing a line between two points, a demonstration that minimising the rate of change of acceleration results in similar strategies (Hogan, 1984) does little to bring understanding to the subject. In contrast a strategy minimising the error in targeting leads to an explanation of Fitt’s Law on the trade-off between accuracy and speed in targeted movements (Harris and Wolpert, 1998) giving real insight into movement strategy. In a similar vein van Soest (1994) showed that optimum strategy in vertical jumping is dependent upon initial position but there exists a strategy that is close to optimal for a wide range of starting positions, suggesting that an element of robustness to change may be included in optimisation strategies adopted by humans. In other words it is likely that human movement strategies are best in the sense that small perturbations do not cause a large degradation in performance. Following this idea Hiley and Yeadon (2003) identified the margin for error for timing release as an important determinant of high bar circling technique in Men’s Artistic Gymnastics. Attempts to assess sensitivity of human performance using a theoretical model are likely to overestimate the sensitivity since if this is a critical element in the performance, the athlete (as opposed to the model) will adopt strategies to reduce the sensitivity. While a theoretical model can attempt to replicate such strategies it will do so in a way that is a simplified representation of the real system and will have less flexibility in the search for robustness of performance in response to perturbations in the timing of muscle contractions, for example.

Postscript

While the case for a particular conclusion may appear clear it should be remembered that research is conducted by humans and that humans are fallible. This is true for the natural sciences no less than for the social sciences. For example in astronomy telescopic observations of Mercury taken at different times showed the same face of Mercury facing the sun and it was concluded that the planet rotated once about its own axis for one revolution about the sun. Since this result was consistent with the theoretical expectation of gravitational lock it was generally accepted as conclusive. The observations, however, were taken at intervals of six months during which Mercury had completed two orbits of the sun (Dyce et al., 1967). Subsequently it was discovered from radar measurements that Mercury rotates three times about its own axis for every two orbits of the sun. As a consequence after an interval of six months Mercury was again in the same orientation. From a theoretical perspective a 3:2 ratio is understandable as well as a 1:1 ratio as in the case of the moon orbiting the Earth. Thus a myopic interpretation of both experimental and theoretical data lead to a false conclusion that was generally accepted from 1882 until 1965.

Our conceptual frameworks constrain the kind of questions that can be formulated and the kind of answers that are considered. The search for a single mathematical optimisation criterion to explain the strategy adopted by the central nervous system to achieve a specific task will give way to somewhat different considerations when it is appreciated that robustness of response to perturbations is necessary. The idea that offspring must exhibit an intermediate blend of parental characteristics persisted in the nineteenth century due to the idea that the world was smooth and continuous rather than discrete and digital. Against this mainstream Darwin noted that offspring were distinctly male or female rather tha ( )Tj 4.5a0 Td (a)Tj 6

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