In search of sports biomechanics' holy grail: Can athlete-specific optimum sports techniques be identified?

Paul S. Glazier [a,*], Sina Mehdizadeh [b]

[a] National Sports Institute of Malaysia, Kuala Lumpur Sports City, Kuala Lumpur, Malaysia
[b] Toronto Rehabilitation Institute, University Health Network, Toronto, Canada

ARTICLE INFO

ABSTRACT

The development of methods that can identify athlete-specific optimum sports techniques—arguably the holy grail of sports biomechanics—is one of the greatest challenges for researchers in the field. This 'perspectives article' critically examines, from a dynamical systems theoretical standpoint, the claim that athlete-specific optimum sports techniques can be identified through biomechanical optimisation modelling. To identify athlete-specific optimum sports techniques, dynamical systems theory suggests that a representative set of organismic constraints, along with their non-linear characteristics, needs to be identified and incorporated into the mathematical model of the athlete. However, whether the athlete will be able to adopt, and reliably reproduce, his/her predicted optimum technique will largely be dependent on his/her intrinsic dynamics. If the attractor valley corresponding to the existing technique is deep, or if the attractor valleys corresponding to the existing technique and the predicted optimum technique are in different topographical regions of the dynamic landscape, technical modifications may be challenging or impossible to reliably implement even after extended practice. The attractor layout defining the intrinsic dynamics of the athlete, therefore, needs to be determined to establish the likelihood of the predicted optimum technique being reliably attainable by the athlete. Given the limited set of organismic constraints typically used in mathematical models of athletes, combined with the methodological challenges associated with mapping the attractor layout of an athlete, it seems unlikely that athlete-specific optimum sports techniques will be identifiable through biomechanical optimisation modelling for the majority of sports skills in the near future.

© 2019 Elsevier Ltd. All rights reserved.

1. Introduction

One of the greatest challenges in sports biomechanics is the development of methods that can identify athlete-specific optimum sports techniques. An understanding of optimum technique—defined by Hatze (1973) as the *"... motions yielding a maximal performance under given constraining conditions and for a given individual ..."* (p. 138)—would provide the basis for augmented knowledge of performance feedback, as a 'template' for the to-be-achieved 'ideal' technique could be constructed for each athlete, performing a particular sports skill, under a particular set of task and environmental constraints (e.g., Ariel, 1985). The movement patterns produced by the athlete could then be compared against this technically 'correct' profile, thereby enabling faults or errors to be objectively identified and remedial action to be unambiguously prescribed (e.g., Hatze, 1983a; Newell and McGinnis,

1985). The importance of identifying a criterion or idealised movement pattern has previously been acknowledged by Newell and Walter (1981), who argued that *"... without a model for deriving comparative information, kinematic feedback would probably prove much less useful"* (p. 242).

There has been some suggestion that athlete-specific optimum sports techniques can be identified through biomechanical optimisation modelling (e.g., Hatze, 1983b; Neptune, 2000; Vaughan, 1984; Yeadon and King, 2018). Indeed, Irwin et al. (2013) stated that biomechanical optimisation modelling *"... is considered the only true method for identifying individualised optimal technique for a particular athlete performing a technically demanding skill."* (p. 159) and Sprigings (1988) argued that biomechanical optimisation modelling provides the *"only solution"* (p. 5) to the problem of establishing whether an elite athlete's technique can be improved to enhance performance and, if so, how. However, the veracity of these claims requires careful consideration, especially in light of the relative paucity of robust examples of successful biomechanical optimisations in the sports biomechanics literature, and recent

theoretical developments in motor control relating to performance optimisation in complex neurobiological systems (e.g., Chow et al., 2009; Glazier and Davids, 2009; Guccione et al., 2019; Loeb, 2012; Seifert et al., 2013). The purpose of this 'perspectives article' is, therefore, to critically examine, from a dynamical systems theoretical standpoint, the efficacy of biomechanical optimisation modelling for identifying athlete-specific optimum sports techniques.

2. Biomechanical optimisation modelling of sports techniques: A view from a dynamical systems theoretical standpoint

The emergence of dynamical systems theory in human movement science and its application to biomechanical optimisation modelling has considerable implications for the identification of athlete-specific optimum sports techniques. This theoretical perspective asserts that the morphology (i.e., shape or form) of evolving movement patterns that define sports techniques is governed by ubiquitous processes of physical self-organisation (Kelso, 1995) and the confluence of interacting organismic, environmental, and task constraints imposed on the athlete (Newell, 1986) (see also Kugler, 1986). Briefly, organismic (e.g., body mass, limb lengths, muscular strength, joint ranges of motion, etc.) and environmental (e.g., gravitational forces, ambient light and temperature, surface compliance, physical characteristics of equipment and apparatus, etc.) constraints are those limiting factors that are endogenous and exogenous to the athlete, respectively, and task constraints are those limiting factors that are related to the goal of the task and the rules governing the task (see Glazier and Robins, 2013, for a summary of the key constraints impacting on sports performance). Constraints can be physical or informational in nature (Warren, 2006) and act to channel and guide the patterns of coordination and control that define technique by eliminating certain limb and torso configurations. Importantly, in the context of this article, Newell (1986) stated that, *"The optimal pattern of coordination and control for a given individual is specified by the interaction of organismic, environmental and task constraints"* (p. 354) and that the *". . . optimal pattern of coordination and control for a given task will be individual specific"* (p. 352) (see Newell, 1985, for operational definitions of coordination and control, and a further elaboration on the role of constraints in the optimisation of movement patterns).

From this theoretical standpoint, it is apparent that a representative set of organismic, environmental, and task constraints needs to be incorporated into the mathematical model of the athlete and surrounding environment, and in the optimisation process in the form of an appropriately weighted optimality criterion or objective cost function, if that athlete's optimum technique is to be identified (Glazier and Davids, 2009; Hu and Newell, 2011). Although this task appears to be extremely challenging, if not impossible, given the constantly fluctuating array of diverse constraints that performance in sport typically presents, the low probability of the same set of constraints occurring more than once suggests that the practical application and functional utility of attempting to identify athlete-specific optimum sports techniques for so-called 'open' sports skills, where task and environmental constraints vary continuously (Poulton, 1957), is limited. However, for so-called 'closed' sports skills, where task and environmental constraints remain relatively constant (Poulton, 1957), and where the probability of the same set of constraints occurring more than once is high, the practical application and functional utility of identifying athlete-specific optimum sports techniques is not only much greater, the computational demands of doing so are more manageable, albeit still considerable. For these reasons, then, it is unsurprising that most previous attempts to identify athlete-specific optimum sports techniques have involved sports skills from this

category. The computational demands of identifying athlete-specific optimum techniques used to perform closed skills integral to sports such as track and field athletics, gymnastics, and diving (e.g., see King and Yeadon, 2015), are further reduced by the fact that these techniques involve a relatively small number of mechanical degrees of freedom and are, thus, comparatively simple to model. Furthermore, tasks constraints are often limited to manipulations of whole-body moments of inertia to control angular velocity and/or to produce a specified movement pattern once an appropriate amount of angular momentum has been generated during the contact phase prior to take-off.
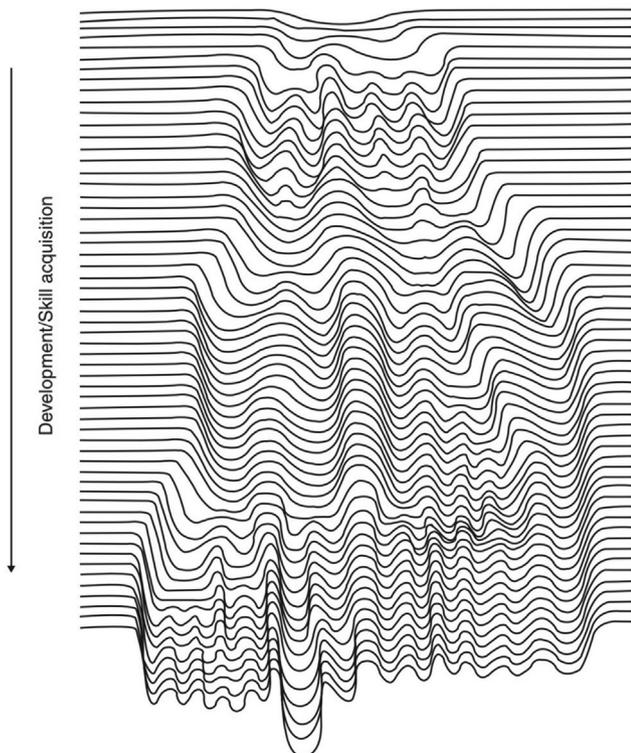
Owing to the relative constancy of task and environmental constraints, the majority of within-athlete and, more markedly, between-athlete technique variability during the performance of closed sports skills can be attributed to fluctuations and variations in functional (i.e., relatively time dependent) and structural (i.e., relatively time independent) organismic constraints, respectively. Accordingly, it is necessary to identify and incorporate a representative set of organismic constraints into the mathematical model of the athlete if this technique variability, which is readily observable within and among even the most elite athletes (e.g., Schöllhorn and Bauer, 1998; Whiting et al., 1991), is to be captured in predicted athlete-specific optimum sports techniques. One strategy adopted in biomechanical optimisation modelling studies to establish whether a mathematical model of an athlete is appropriately constrained is to simulate one or more performance trials performed by that athlete. If the simulated movement patterns and the movement patterns of the performance trial(s) match within acceptable bounds, the model is deemed to be valid. However, as Panjabi (1979) highlighted, just because simulated movement patterns match the movement patterns of an actual performance trial, it does not guarantee that the predicted optimum movement pattern, or any other simulated movement patterns for that matter, will be valid. For example, it is possible to fit a set of joint torques to a mathematical model that does not accurately represent the inertial characteristics of the athlete and still get simulations that approximate the performance trials, but the predicted optimum technique (i.e., the movement pattern that corresponds with the set of joint torques that maximises the performance criterion) is likely to be erroneous. Additionally, non-linearities in some organismic constraints, especially those of the neuromuscular system, which Hatze (1983b) argued ". . . *are responsible for most of the peculiar characteristics of optimal sports motions"* (p. 6), also need to be accurately represented if predicted athlete-specific optimum sports techniques are to be valid.

Another important consideration in relation to the practical application and functional utility of identifying athlete-specific optimum sports techniques is whether the athlete will be able to adopt, and reliably reproduce, his/her predicted optimum movement pattern, particularly during the often-intense psychological pressures of competition where it is known that stress and anxiety can adversely affect patterns of coordination and control (e.g., Beilock and Gray, 2007). In addition to inherent within-athlete technique variability that prevents the same movement pattern from being repeated twice (e.g., Davids et al., 2003; Newell and Slifkin, 1998; Preatoni et al., 2013), a key concept from dynamical systems theory, which is applicable here and related to the aforementioned constraints issue, is 'intrinsic dynamics'. Corbetta and Vereijken (1999) defined intrinsic dynamics as the ". . . *spontaneous coordination tendencies or preferred modes of coordination that exist in the movement system at the start of the learning process. In other words, intrinsic dynamics capture the initial state of an organism when faced with a new learning or developmental task, reflecting the history of the system and prior experiences that contribute to form the existing behavioural repertoire.*" (p. 511). The intrinsic dynamics of an athlete can be depicted schematically as a dynamic landscape

(Fig. 1). This three-dimensional graphic provides a visual representation of how stable movement patterns, denoted by the valleys or attractor regions of the landscape, develop and change over the lifespan. The collection of attractor states at the fore of the landscape characterise the current movement repertoire of the athlete.

Two factors that will largely determine whether an athlete will be able to reliably adopt his/her predicted optimum technique are: (i) the stability of the attractor corresponding with the existing sub-optimum technique; and (ii), the proximity of the attractors corresponding with the existing sub-optimum technique and the to-be-achieved predicted optimum technique (see Zanone and Kelso, 1992, and Kostrubiec et al., 2012, for similar arguments based on experiments of bimanual coordination). As motor learning is characterised by the moulding and sculpting of pre-existing attractor states that define the athlete's intrinsic dynamics (Kelso, 1995), deep valleys or valleys that are situated in different topographical regions of the dynamic landscape are problematic in that they are more difficult to extricate from or shift between, respectively. Consequently, in both scenarios, any technical modifications prescribed based on biomechanical optimisation modelling may be challenging or impossible to reliably implement even after extended practice. Although a 'scanning probe' has been used to map the attractor layout comprising the dynamic landscape of individuals participating in bimanual coordination studies (e.g., Zanone and Kelso, 1992), this procedure would be methodologically challenging if applied to sports techniques due to their typically discrete and multiarticular nature. Accordingly, establishing the likelihood of the predicted optimum technique being reliably attainable is difficult.

One final point to consider is whether the technique already being adopted by the athlete is truly sub-optimum. In effect, the assumption being made is that the existing technique is only a local optimum in the dynamic landscape and that, through biomechanical optimisation modelling, a superior technique representing the global optimum, can be identified and then subsequently adopted. However, given the many hours of deliberate practice that elite athletes, in particular, engage in during their sporting careers, it is conceivable that many of them have gone through a long process of self-optimisation and are already adopting their own optimum technique (e.g., Cavanagh and Hinrichs, 1981). Any marked differences between the predicted optimum technique and the existing technique may, therefore, just reflect discrepancies between the constraints comprising the mathematical model of the athlete and those of the actual athlete rather than faults or errors characterising a sub-optimum technique. Theoretically, if the constraints of the actual athlete, including those that govern the intrinsic dynamics, matched those of the mathematical model of the athlete, the predicted optimum technique would replicate the existing technique being adopted by the athlete. A key task, then, is to establish which constraints are modifiable and what the effect on performance is should these constraints be removed or relaxed.

3. Concluding remarks

The virtues of biomechanical optimisation modelling have regularly been highlighted in the sports biomechanics literature and it remains a useful tool for establishing cause and effect relationships between the underlying kinetic mechanisms and the observable kinematics. However, based on the arguments presented in this article, and those presented by us (Glazier and Mehdizadeh, 2019) and others (e.g., Bobbert and Casius, 2011) elsewhere, sports biomechanists are still some way from being able to identify athlete-specific optimum techniques in the majority of sports. Furthermore, even if it were more readily possible, it is open to question whether the athlete would be able to adopt and reliably reproduce the specified movement patterns because of that athlete's unique intrinsic dynamics. The inclusion of a more representative set of organismic constraints, along with their non-linear characteristics, in mathematical models of athletes is a necessary prerequisite if the identification of achievable athlete-specific optimum sports techniques is to be realised. The recognition of the need to include more representative organismic constraints into mathematical models used in sports biomechanics is not new, however. For example, Baumann (1987) argued, *"If biomechanics is not capable of incorporating more of the essential anatomical and neurophysiological characteristics of the human body, it does not deserve its prefix 'bio' and it will not arrive at its real goals"* (p. 57). Until then, sports biomechanists, coaching practitioners, and other key stakeholders should heed the warning of Hay (1983), who stated, *". . . we would all be wise to view mathematical modelling studies with caution. Certainly we should not accept the extravagant claims—occasionally made on television and in the popular press—that, through modelling, sports biomechanists can now determine the optimum technique for a given athlete. These claims are science fiction not science fact."* (p. 18). Although great advancements have undoubtedly been made in biomechanical optimisation modelling of sports techniques in the last 35 years, these remarks appear to be as relevant today as they were back then.

Declaration of Competing Interest

None.

References

Ariel, G.B., 1985. Biofeedback and biomechanics in athletic training. In: Sandweiss, J. H., Wolf, S.L. (Eds.), Biofeedback and Sports Science. Plenum Press, New York, pp. 107–145.

Fig. 1. The evolving dynamic landscape (also known as the attractor landscape or perceptual-motor workspace) defining the developmental history and current movement repertoire of an athlete (adapted from Muchisky et al., 1996).

Baumann, W., 1987. Biomechanics of sports - current problems. In: Bergmann, G., Kölbel, R., Rohlmann, A. (Eds.), Biomechanics: Basic and Applied Research. Martinus Nijhoff, Dordrecht, pp. 51–58.

Beilock, S.L., Gray, R., 2007. Why do athletes choke under pressure? In: Tenenbaum, G., Eklund, R.C. (Eds.), Handbook of Sport Psychology. 3rd ed. Wiley, Hoboken, NJ, pp. 425–444.

Bobbert, M.F., Casius, L.J.R., 2011. Can forward dynamic simulation models be used to improve the performance of top athletes? Proceedings of the 29th International Symposium on Biomechanics in Sports. Porto, Portugal.

Cavanagh, P.R., Hinrichs, R., 1981. Biomechanics of sport: The state of the art. In: Brooks, G.A. (Ed.), Perspectives on the Academic Discipline of Physical Education. Human Kinetics, Champaign, IL, pp. 137–157.

Chow, J.Y., Davids, K., Button, C., Rein, R., Hristovski, R., Koh, M., 2009. Dynamics of multi-articular coordination in neurobiological systems. Nonlinear Dyn. Psychol. Life Sci. 13, 27–55.

Corbetta, D., Vereijken, B., 1999. Understanding development and learning of motor coordination in sport: The contribution of dynamic systems theory. Int. J. Sport Psychol. 30, 507–530.

Davids, K., Glazier, P., Araújo, D., Bartlett, R., 2003. Movement systems as dynamical systems: The functional role of variability and its implications for sports medicine. Sports Med. 33, 245–260.

Glazier, P.S., Davids, K., 2009. Constraints on the complete optimization of human motion. Sports Med. 39, 15–28.

Glazier, P.S., Robins, M.T., 2013. Self-organisation and constraints in sports performance. In: McGarry, T., O'Donoghue, P., Sampaio, J. (Eds.), Routledge Handbook of Sports Performance Analysis. Routledge, London, pp. 42–51.

Glazier, P.S., Mehdizadeh, S., 2019. Challenging conventional paradigms in applied sports biomechanics research. Sports Med. 49, 171–176.

Guccione, A.A., Neville, B.T., George, S.Z., 2019. Optimization of movement: A dynamical systems approach to movement systems as emergent phenomena. Phys. Ther. 99, 3–9.

Hatze, H., 1973. Optimization of human motions. In: Cerquiglini, S., Venerando, A., Wartenweiler, J. (Eds.), Biomechanics III – 3rd International Seminar on Biomechanics, Rome. Karger, Basel, pp. 138–142.

Hatze, H., 1983a. Myocybernetic optimization of sports motions – model, methods for parameter identification, practical implementation. In: Baumann, W. (Ed.), Biomechanics and Performance in Sport. Hofmann, Schorndorf, pp. 173–182.

Hatze, H., 1983b. Computerized optimization of sports motions: An overview of possibilities, methods and recent developments. J. Sports Sci. 1, 3–12.

Hay, J.G., 1983. Biomechanics of sport: An overview. In: Wood, G. (Ed.), Collected Papers on Sports Biomechanics. University of Western Australia Press, Nedlands, WA, pp. 1–21.

Hu, X., Newell, K.M., 2011. Modeling constraints to redundancy in bimanual force coordination. J. Neurophysiol. 105, 2169–2180.

Irwin, G., Bezodis, I., Kerwin, D., 2013. Biomechanics for coaches. In: Jones, R.L., Kingston, K. (Eds.), An Introduction to Sports Coaching: Connecting Theory and Practice. Routledge, London, pp. 145–160.

Kelso, J.A.S., 1995. Dynamic Patterns: The Self-Organization of Brain and Behavior. MIT Press, Cambridge, MA.

King, M.A., Yeadon, M.R., 2015. Advances in the development of whole-body computer simulation modelling of sports technique. Movement Sport Sci. 90, 55–67.

Kostrubiec, V., Zanone, P.G., Fuchs, A., Kelso, J.A.S., 2012. Beyond the blank slate: Routes to learning new coordination patterns depend on the intrinsic dynamics of the learner—experimental evidence and theoretical model. Front. Hum. Neurosci. 6, 222. https://doi.org/10.3389/fnhum.2012.00222.

Kugler, P.N., 1986. A morphological perspective on the origin and evolution of movement patterns. In: Wade, M.G., Whiting, H.T.A. (Eds.), Motor Development in Children: Aspects of Coordination and Control. Martinus Nijhoff, Dordrecht, pp. 459–525.

Loeb, G.E., 2012. Optimal isn't good enough. Biol. Cybern. 106, 757–765.

Muchisky, M., Gershkoff-Stowe, L., Cole, E., Thelen, E., 1996. The epigenetic landscape revisited: A dynamic interpretation. In: Rovee-Collier, C., Lipsitt, L.P. (Eds.), Advances in Infancy Research, Vol. 10. Ablex Publishing, Norwood, NJ, pp. 121–159.

Neptune, R.R., 2000. Computer modeling and simulation of human movement: Applications in sport and rehabilitation. Phys. Med. Rehabilit. Clin. North America 11, 417–434.

Newell, K.M., Walter, C.B., 1981. Kinematic and kinetic parameters as information feedback in motor skill acquisition. J. Human Movement Stud. 7, 235–254.

Newell, K.M., 1985. Coordination, control and skill. In: Goodman, D., Wilberg, R.B., Franks, I.M. (Eds.), Differing Perspectives in Motor Learning, Memory, and Control. North-Holland, Amsterdam, pp. 295–317.

Newell, K.M., McGinnis, P.M., 1985. Kinematic information feedback for skilled performance. Human Learn. 4, 39–56.

Newell, K.M., 1986. Constraints on the development of coordination. In: Wade, M.G., Whiting, H.T.A. (Eds.), Motor Development in Children: Aspects of Coordination and Control. Martinus Nijhoff, Dordrecht, pp. 341–360.

Newell, K.M., Slifkin, A.B., 1998. The nature of movement variability. In: Piek, J.P. (Ed.), Motor Behavior and Human Skill: A Multidisciplinary Approach. Human Kinetics, Champaign, IL, pp. 143–160.

Panjabi, M., 1979. Validation of mathematical models. J. Biomech. 12, 238.

Poulton, E.C., 1957. On prediction in skilled movements. Psychol. Bull. 54, 467–478.

Preatoni, E., Hamill, J., Harrison, A.J., Hayes, K., van Emmerik, R.E.A., Wilson, C., Rodano, R., 2013. Movement variability and skills monitoring in sports. Sports Biomech. 12, 69–92.

Schöllhorn, W.I., Bauer, H.U., 1998. Identifying individual movement styles in high performance sports by means of self-organizing Kohonen maps. In: Riehle, H.J., Vieten, M.M. (Eds.), XVI International Symposium on Biomechanics in Sports (21–25 July, 1998 – Konstanz, Germany). University of Konstanz, Germany, pp. 574–577.

Seifert, L., Button, C., Davids, K., 2013. Key properties of expert movement systems in sport: An ecological dynamics perspective. Sports Med. 43, 167–178.

Springings, E.J., 1988. Sport biomechanics: Data collection, modelling, and implementation stages of development. Can. J. Sport Sci. 13, 3–7.

Vaughan, C.L., 1984. Computer simulation of human motion in sports biomechanics. In: Terjung, R.L. (Ed.), Exercise and Sport Sciences Reviews, Vol. 12. The Collamore Press, Lexington, MA, pp. 373–416.

Warren, W.H., 2006. The dynamics of perception and action. Psychol. Rev. 113, 358–389.

Whiting, W.C., Gregor, R.J., Halushka, M., 1991. Body segment and release parameter contributions to new-rules javelin throwing. Int. J. Sport Biomech. 7, 111–124.

Yeadon, M.R., King, M.A., 2018. Computer simulation modelling in sport. In: Payton, C.J., Burden, A. (Eds.), Biomechanical Evaluation of Movement in Sport and Exercise: The British Association of Sport and Exercise Sciences Guide. Routledge, London, pp. 221–254.

Zanone, P.G., Kelso, J.A.S., 1992. Evolution of behavioral attractors with learning: nonequilibrium phase transitions. J. Exp. Psychol. Hum. Percept. Perform. 18, 403–421.