Biomechanical basis for differential learning in alpine skiing

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1 Introduction

In teaching, mastering, and practicing alpine skiing, learning on the basis of a model is most common. Often the world's present-day best athletes are used as models. Depending on the scientist's point of view, certain characteristics of the athlete are considered and analysed in detail by means of specific variables. Typically, when the diagnosis for a trained athlete exceeds a certain range of tolerance with respect to a chosen variable, the movement of the trained athlete is modified towards the model's ideal values byway of numerous repetitions and corrective instructions. This athlete independent approach leads to problems in connection with the identification of athletes on the basis of their movements (Schöllhorn Nigg Stefanyshyn Liu 2003; Schöllhorn Bauer 1998). Obviously, although all world class athletes are moving themselves within the limits of biomechanically optimal boundary conditions and they never repeat a movement twice, obviously there is still an enormous amount of possibilities to achieve world class level. A recently developed approach that takes advantage of these characteristics is the differential learning approach by Schöllhorn 1999; 2006, which enforce the learning processes by means of the basis of individuality and non-repeatability. By adding stochastic perturbations to the to-be-learned movement, the athlete is forced to enlarge his movement repertoire significantly by receiving new instructions all the time. Furthermore, the athlete never repeats a movement twice, and he never receives corrective instructions.

This article will provide insight with regard to the contradictions between the generalized or athlete independent and the individualized approach.

2 Methods

To describe the biomechanical frame of alpine skiing, a deduction tree is chosen. The deduction tree in sports has been applied in different kinds of sports (Hay1985; Ballreich 1986). In principle, the deduction tree establishes a hierarchy among the biomechanical variables of influence with different target and explanation levels whereby the lower level forms the basis of explanation for the higher level.

3 Results

In the case of alpine skiing for all types of competitions (downhill, slalom, giant slalom or super-G), the primary goal is the minimization of the race time.

Therefore, it seemed plausible to select the running time T_{total} on the highest level as the biomechanical target variable (Fig. 1). On a first explanation level, the total running time T_{total} is divided into part times $\Delta t_1, \ldots, \Delta t_n$. On the next explanation level, each part time t_i is considered as a result of the distances $\Delta s_1, \ldots, \Delta s_n$, and the velocities $\Delta v_1, \ldots, \Delta v_n$ of the athlete that were needed for this race section. In contrast to strong hierarchical deduction trees in alpine skiing, not only do we have connections between different explanation levels, but also within: for example, a shorter distance Δs_i in a section can lead to a longer distance Δs_{i+1} and/or longer time Δt_i in one of the subsequent sections. The same is valid for velocities Δv_i and time intervals Δt_i on the higher explanation level. In the next step, an intermediate explanation level 3a and 3b for the velocities Δv_i is included. In this level, accelerating and breaking, or friction forces, are introduced as the physical basis for changes in the velocities Δv_i. Within the accelerating forces the downhill and the pushing force are distinguishable. The air resistance force and the adhesion forces are forms of breaking forces. On the fourth level of explanation, the variables are clustered mainly into three groups in relation to the athlete, the equipment and the environment (Fig 1).

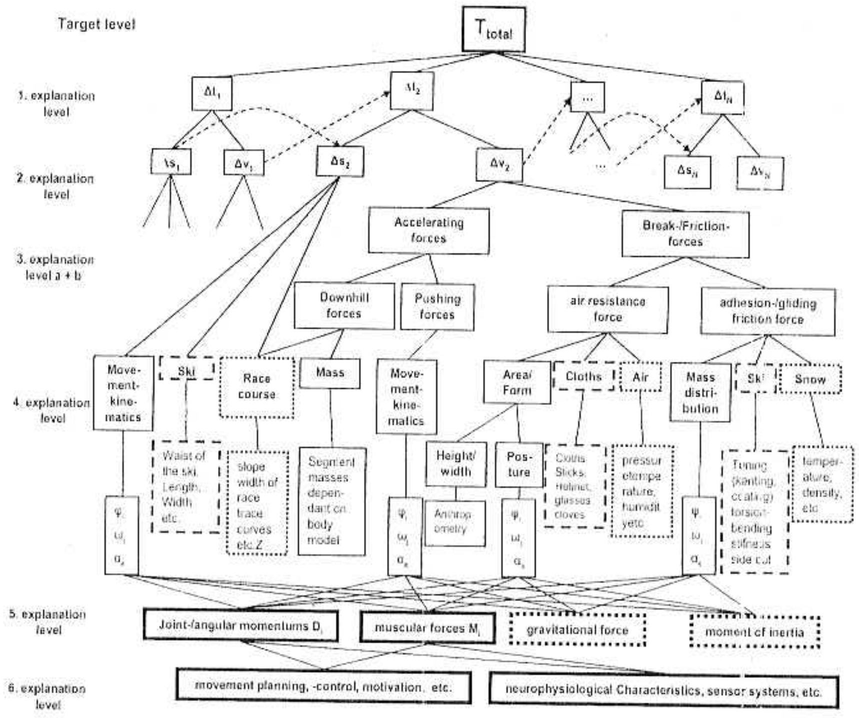

Fig. 1: Deduction tree of skiing performance on the basis of biomechanical variables in alpine skiing

Going on to the next explanation level, changes in the covered distances can be explained by kinematic variables of the athlete, by variables of the skis and variables of the geometry of the race course (Fig. 2).

Skiing athlete

- Movement kinematics
  - Joint angle i
  - Joint angular velocity i
  - Joint angular acceleration i

  (i=number of relevant joints)
- Movement dynamics
  - Angular momentums k
  - Muscle forces k
- Neuromuscular characteristics
  - Nerve conducting velocity
  - Muscle fibre distribution
  - ...
- Anthropometry
  - Body Height
    - Segment lengths
  - Body mass
    - Segment masses
  - Relations
  - ...

Equipment

- Clothing
  - a) Helmet
  - b) Suit
  - c) Glasses
  - d) Cloves
  - e) Shoes
  - f) ...
- Poles
- Skis
  - a) Bending stiffness
  - b) Torsion stiffness
  - c) Waist of the ski
  - d) Length
  - e) Width
  - f) Ski-Tuning
  - g) ...

Environment

- Snow
  - Temperature
  - Density
  - ...
- Weather
  - Air pressure
  - Air humidity
  - Temperature
  - Direction of wind
  - Velocity of wind
  - ...
- Altitude
- Topography

Fig. 2: Three clusters of biomechanical variables

In the first place, the race course and its variables (slope, width, and curves of the race trace) determine the covered distance Δs_i. Within the given race conditions, the kinematic variables reflect the athlete's movement and his or her choice of race course that corresponds to a cross connection within the same level of explanation. Similarly, the ski variables influence the geometry of the race path by their side cut, bending or torsion stiffness, length and width of the skis. At the same time, the race course variables are part of the explanation for the downhill forces and therefore, influence the velocity changes Δv_i as an accelerating force.

Influence on the downhill forces also is provided by personal variables such as body mass that can only be influenced by the athlete over a longer time scale that is longer than the duration of a single race. A specific force of acceleration is the pushing force that mainly occurs during the starting phase or in case of too small downhill forces or too large breaking forces.

The breaking force of the air resistance analogously is dependant on the geometry of the athlete's posture, the clothing of the athlete and the physical characteristics of the air itself. The most important physical variables that influence the characteristics of the air and therefore, its contribution to the air resistance are air pressure (altitude), temperature, humidity and wind (amount and direction). The clothes, including helmet, racing suit, gloves, etc., contribute to the air resistance as a result of the air friction on their surface material and the resulting turbulences. An active influence of the athlete on air resistance is provided by the posture, which is closely connected to the movement kinematics and the height and body size of the athlete.

The second group of breaking forces, while probably the most important forces during high performance skiing and the most versatile parameter of influence, is the adhesion and gliding friction forces that are influenced by the kinematics of the athlete, the skis and the snow. Moreover, the characteristics of the snow are influenced by the temperature, the humidity, the density and the grain of the snow. (Lind & Sanders 2006)). Parameters of the skis are the length and the width, as well as the side cut of the skis, their bending and torsion stiffness, the preparation of the edges and the gliding surface, etc. The contribution of the athlete to these friction forces is primarily provided by means of his or her active mass distribution on and edging of both skis. Most intriguing and complicated is how these parameters interact with each other. Not only do they interact within their own group, but also with parameters of the air resistance force and with variables that explain changes of the covered distance Δs_i.

Some examples of interaction within the same explanation level are shown in the following.

By loss of altitude during a race the characteristics of snow are changing because of the rising temperature and higher air pressure. Consequently, the conditions of the snow change as well, thereby changing the depth of penetration of the skis.

Different depths of penetration lead to different bending of the skis, which in turn results in different radii of the curves. Additionally, the varying snow characteristics often are accompanied by changes in the friction resistance. This leads to a slowing down of the skis relative to the athlete, which forces instantaneous adaptations in the kinematics of the athlete. These changes can eventually lead to modifications in posture, which result in changes of air resistance, which in turn, alters the relative movements of both the skis and the athlete. For a more detailed analysis of the biomechanics of skiing in general, and biomechanics of carving in particular, see (Lind et al., 2006), (Jentschura & Fahrbach, 2004) (Niessen & Müller, 1999).

According to Newtonian physics on an even lower level of explanation, all the athlete related kinematic parameters can be explained by way of joint angular momentums, muscular, gravitational and inertial forces. On a rather psychological or anatomical explanation level, there is a relation between the forces and motivation, social environment, genetics, etc. A characteristic of the deduction tree is the lower the explanation level, the higher the indeterministic character. While the higher explanation levels are rather deterministic, the lower levels become more and more uncertain. In general, this deduction tree can be considered as a coarse qualitative basis for the development of quantitative biomechanical and physical models. Traditionally, such quantitative biomechanical models assume a unique and optimal solution for most of the variable's relation. In correspondence with classical pedagogical models, a single optimum solution is assumed and very often provides the basis for the learning and teaching by a model according to (Bandura & Walters, 1963).

In contrast to this traditional approach, where someone is trying to copy a model by numerous repetitions, the differential learning approach (Schöllhorn, 1999); (Schöllhorn et al., 2006) is based on nonlinear system dynamics and assumes an individual and constantly changing optimum for each athlete. The assumption of an individual optimum is based on the identification of athletes by means of their process oriented movement pattern during 200ms. The analysis of the final throwing phase of world class javelin throwers (Schöllhorn & Bauer, 1998), as well as the analysis of the ground contact phase in gait revealed highly individual movement patterns (Schöllhorn, Nigg, Stefanyshyn, & Liu, 2002) that resulted in recognition rates from 95-99%. Most intriguingly, the individuality was recognizable over several years in the javelin throwers and in the gait patterns despite heel height changes of up to 5.4cm. In accordance with the assumption of (Bernstein, 1967) about repeating without repetition, and the theoretical reflections of (Hatze, 1986) about variability, the differential learning approach emphasizes the training of the ability to adapt to the new part of the next movement repetition by never repeating a movement or an instruction twice. Thereby, typically stochastic perturbations are added to a to-be-learned movement in order to increase the amount of fluctuations that occur during normal movement repetitions. Adding stochastic perturbations corresponds to noisy learning in Artificial Neural Nets and serves for spanning a coarse meshed net over the potential space of solutions in order to rely on the athlete's ability to interpolate between the learned nodes. Figure 3a-c schematically displays the basis for such adaptive learning. We should keep in mind however, that all trials of all athletes are accomplished within the biomechanical optimum boundary conditions. If the same turn of several athletes A ... N were repeated within a series and they were compared with each other, we would be able to distinguish each trial of each athlete and we would recognize the differences between the techniques of each athlete (Fig. 3a).

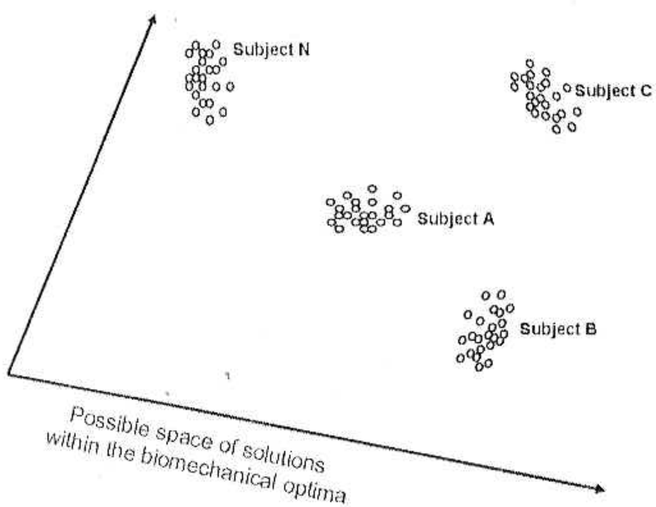

Fig. 3a: Movement repetitions of four skiing athletes within the possible space of biomechanically optimum solutions

If the series of repetitions were repeated on another day 1 ... , all trials would be slightly different from all others (according to Heraklits aphorism "you will

never step into the same river twice") and they would be separable for each individual again (Fig 3b).

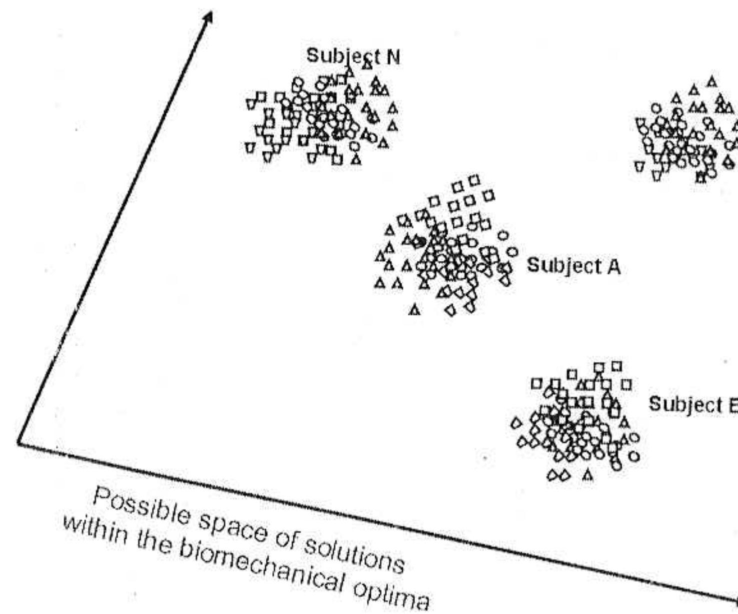

Fig. 3b: Movement repetitions of four skiing athletes on four different days within the possible space of biomechanically optimum solutions

In addition to other causes, these changes might be the result of emotional fluctuations ((Janssen et al., 2008) or fatigue (Jäger, Alichmann, & Schöllhorn, 2003). At minimum, these differences provide clear evidence for a revision of the system, and the amount of modification of the system appears to be dependant on the time scale. It hardly would be possible to cover the whole space of viable solutions by simply repeating a ski turn technique because the next movement will inherit something new again. Alternatively, the space of possible solutions that will be touched with high probability in the future can be scanned in a kind of a coarse mesh sized net where a larger space will be covered by less exercises (Fig 3c).

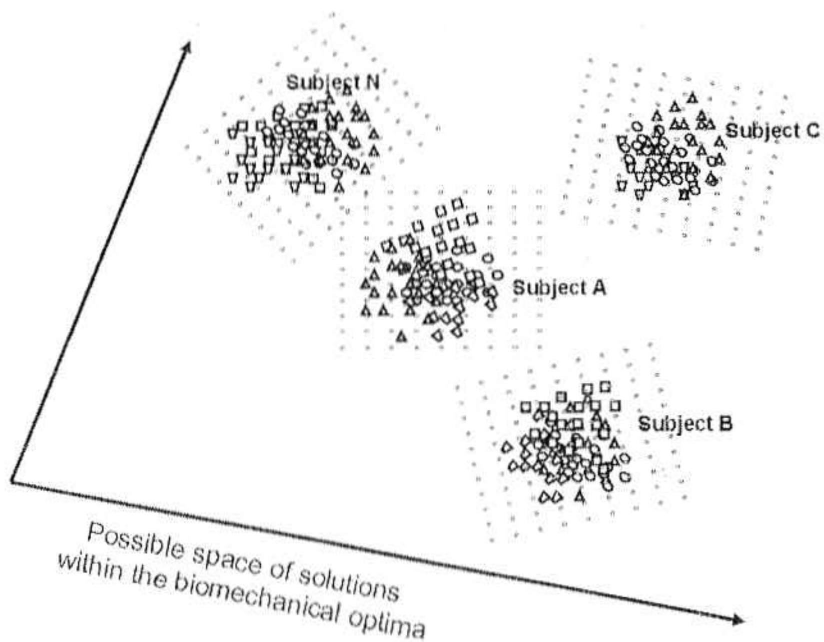

Fig. 3c: Movement repetitions of four skiing athletes on four different days within the possible space of biomechanically optimum solutions with coarse meshed training net

With this approach, the athlete can take advantage of the neuro-muscular system's ability to interpolate between two known states. For example, this ability is used from our visual system to "hide" our blind spot during all day's visual recognition. Because the changes within one athlete from day to day are probably individual, it seems reasonable that every athlete or coach has to find his or her own optimum net with optimum mesh size in order to optimize the training process. However, training in a net like this, as it corresponds to the differential learning approach and numerous approaches in artificial intelligence, suggests a much larger variability than in traditional approaches.

All in all, especially the uncertainty on the lower levels of the biomechanical deduction tree provides the basis and plausible necessity/connection for the differential learning approach according to learning approaches in artificial intelligence (Miglino, Lund, & Nolfi, 1995). Success of the differential learning approach in numerous other types of sports (Beckmann & Schöllhorn, 2003; Schöllhorn et al., 2006) should at least encourage us to call into question the assumptions and consequences of traditional approaches in alpine sports.

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Cumulative muscle fatigue during recreational alpine skiing

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1 Introduction

Numerous authors have reported that muscle contraction forces can reach upwards of 150% of maximal voluntary contraction (MVC) when making a turn [2,4,15,24]. Szmedra et al. [21] observed significant levels of muscle ischemia and hypoxia when racers completed slalom turns. The combined effects of high forces, substrate depletion, ischemia, and hypoxia leads to increased muscle stress during skiing as noted by the increase in creatine kinase levels (CK) [18].

Heart rate (HR), blood lactate (LA), myoglobin, and cortisol have also been used to assess the acute stress levels of an activity. Krautgasser et al. [6] and Scheiber et al. [17] reported blood LA of about 2 mmol/L and skiing HR of about 80% maximal of heart rate (HRmax) during skiing in older recreational skiers. In contrast, race training significantly increases skiing HR over that of recreational skiing. Heart rate during giant slalom training has been reported to be between 87% and 97% of maximal HR [3,19].

On a typical ski day, skiers will ski about 3 hours in the morning, take a lunch break, and then ski for 2-3 more hours in the afternoon. With thousands of repeated contractions occurring during a day of skiing, some level of fatigue is inevitable. However, the risk of injury increases with fatigue and reduces the pleasure of the activity [1,5,9,10,12]. Identifying and understanding the physiological responses to fatigue, improvements in the sports equipment used in the activity, changing work/rest ratios of the activity, and employing nutritional interventions are helpful in not only improving the comfort and enjoyment of skiing, but also enhancing the training and safety associated of this activity.

It is important to understand how a specific activity can change the various physiological indices associated with fatigue. For example, in activities such as cycling and running, HR and blood LA levels are positively correlated to and