SCIENCE AND SKIING VII

Edited by

Erich Müller
Josef Kröll
Stefan Lindinger
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Jörg Spörri
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Science and Skiing VII

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Introduction

The 7th International Congress on Science and Skiing was held at St. Christoph am Arlberg, Tyrol, Austria, in December 2016. It was the follow-up conference of the first six International Congresses on Skiing and Science, five of which were also held in St. Christoph a. A., Austria, in 1996, 2000, 2007, 2010 and 2013.

The conference was organized and hosted by the Department of Sport Sci-ence at the University of Salzburg, Austria. During this congress the 20th anniversary of the International Science and Skiing Movement was celebrated.

The scientific program offered a broad spectrum of current research work in Alpine and Nordic skiing and in snowboarding. The highlights of the congress were four excellent keynote sessions. The scientific program of the congress was completed by 97 oral and 44 poster presentations.

In the proceedings of this congress, two keynotes and most of the oral presentations are published. The manuscripts were subject to peer review and editorial judgement prior to acceptance.

We hope that these congress proceedings will again stimulate many of our colleagues throughout the world to enhance research in the field of skiing so that at the Eigth International Congress on Science and Skiing, which will be organized in spring 2019 in Vuokatti, Finland, many new research projects will be presented.

Erich Müller
Josef Kröll
Stefan Lindinger
Jürgen Pfusterschmied
Jörg Spörri
Thomas Stöggl

We would like to express our cordial thanks to Julia Stöggl for the time and the energy which she invested in the editing of this book.

Part One
Keynote Papers

ALPINE SKIING AND CARDIO-METABOLIC HEALTH

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Keywords: skeletal muscle fiber type, inflammation, insulin sensitivity, blood lipids, capillarization

Introduction

In the past several decades, there has been a decline in daily physical activity, both at work and in leisure time. The impact of a population doing fewer and fewer physically demanding activities, thereby increasing inactivity time, has obvious and well-documented health consequences. Related to this is the loss of skeletal muscle mass that may follow aging (i.e., sarcopenia). The etiology of sarcopenia is simple: It is a disuse disease, which may trigger a cascade of vicious circles in which particular cardio-metabolic diseases develop and thrive. To avoid inactivity-related diseases in the aging population, the crucial timeframe is some years before the time of retirement. At this point, exercise habits should be established, acknowledging that the level of physical activity at the age of 70 is a strong determinant for disability at age 75.

It is also well established that increased physical activity improves insulin sensitivity, lipid profile, and blood pressure, and has beneficial effects on cardio-metabolic diseases. There is a strong inverse relationship between cardiorespiratory fitness and the metabolic syndrome. There is no particular form of exercise or sports activity which is better than the other; the exercise that works best is the one that is actually being done.

Alpine skiing offers an attractive possibility, and it is unique in its simultaneous training of both strength and aerobic capacity. This sport seems well suited for elderly, otherwise sedentary people who are in need of improvements in muscle mass, strength, and aerobic capacity. Alpine skiing can be performed as a leisure-time activity, but also as a specific rehabilitation approach after surgical procedures (Kristensen et al., 2015).

Results and Discussion

Cardiorespiratory fitness

Maximal oxygen uptake (VO_{2max}) integrates the important components not only in the cardiorespiratory system, but also in the metabolic domain. These components include the pulmonary system (ventilation and gas diffusion); the heart and circulation (hemoglobin, blood volume, cardiac output, arterial pressure); peripheral perfusion of active skeletal muscle (blood vessel size, capillarization); and organs and non-active skeletal muscle, as well as energy expenditure and metabolism (muscle mass, muscle fiber types, substrate availability, mitochondrial respiratory capacity). Of these components, which are all potential limiting factors for VO_{2max}, studies have clearly shown that cardiac output is the most important factor in healthy humans.

VO_{2max} is also a very good predictor for health outcomes, even in diseased patients. In a unique study from Finland, 1,294 healthy men and 1,057 men with various diseases—including coronary heart disease, heart failure, claudication, stroke, arrhythmia, chronic obstructive pulmonary disease, and cancer—had peak maximal oxygen uptake measured and were then followed for thirteen years (Laukkanen, Kurl, Salonen, Rauramaa, & Salonen, 2004). Outcomes were overall mortality and fatal and non-fatal cardiac events. The data showed clearly that maximal oxygen consumption was a powerful predictor of future fatal cardiac events and, more importantly, that in the unhealthy men, the influence of classical risk factors (e.g., smoking, hypertension, obesity) became negligible (Laukkanen et al., 2004). Thus, maximal oxygen consumption is more important than classical risk factors in the prediction of future health outcomes. Other studies that included women have confirmed the effect of daily physical activity in reducing the mortality risk of cardiovascular disease and even cancer. Therefore, any form of physical activity that increases maximal oxygen uptake is beneficial for health.

Muscle and metabolism

Muscular strength peaks between the second and fourth decades and declines thereafter as a result of muscle fiber atrophy and loss of motor units; eventually sarcopenia may develop. This loss of muscle mass and strength can be markedly delayed by just moderate resistance training, which counteracts the development of muscular frailty and may be initiated even at advanced age.

With aging, there is a risk of the development of a vicious cycle with the inevitable loss of strength and aerobic capacity leading to a decline in physical activity, which in turn further accelerates the deterioration of muscle mass, power, and physical capacity. The loss of strength and aerobic fitness with aging coincides with the increasing prevalence of chronic diseases including components of the metabolic syndrome such as obesity, atherosclerosis, and type-2 diabetes, and it is likely that a causal relationship exists between aerobic capacity and muscular strength and the metabolic syndrome (Chakravarthy & Booth, 2004). Furthermore, muscle mass, strength, and aerobic capacity are inversely related to overall morbidity and mortality risk (Ruiz et al., 2008).

Alpine skiing is unique in its simultaneous training of both muscle and aerobic capacity. The question is whether recreational alpine skiing is sufficient to bring about significant adaptations in an elderly cohort.

Is alpine skiing cardiorespiratory training?

In a recent study by Stöggl et al. (2016), alpine skiing, cross-country skiing, and classical ergometer bicycling were compared in their ability to achieve an exercise intensity and energy expenditure which would be sufficient to increase VO_{2max}. Ergometer bicycling can be calibrated accurately to match a given exercise intensity, and cross-country skiing can also be adjusted (via changing speed) to given work intensities. However, alpine skiing is more difficult to perform at a given exercise intensity, but by using different skiing techniques (e.g., parallel ski steering, carving long turn, short-turn skiing), the workload was calibrated to match a predetermined relative intensity (figure 1).

The experiment was successful in the sense that a relative workload of 70, 80, and 90% was achieved in all three exercise modalities. The peak oxygen uptake during the different exercise modalities and intensities are shown in figure 1.

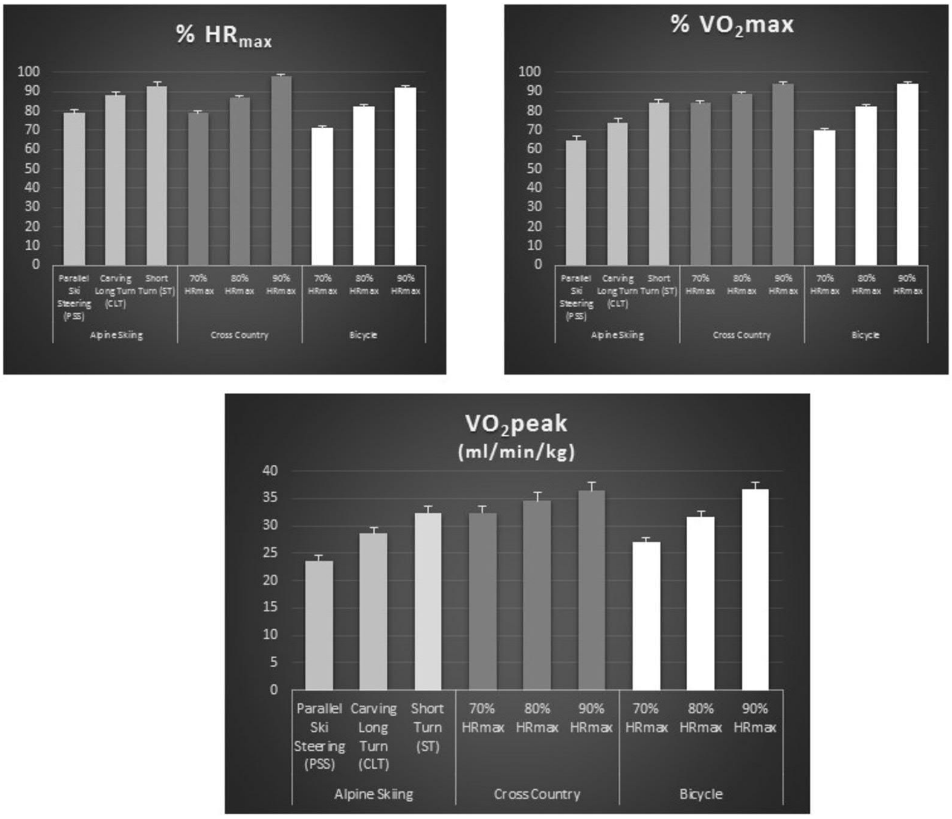

Figure 1 *Data from Stöggl et al. (2016). Measurements of percent maximal heart rate (top left), percent VO_{2max} (top right), and VO_{2peak} (bottom) during alpine skiing (different techniques), cross-country skiing at different speeds, and bicycling.*

The interesting conclusion from this study is that with alpine skiing it is possible to achieve workloads that will increase VO_{2max}. However, due to the nature of alpine skiing, the exercise is not constant for long periods of time, but interrupted by rest while sitting in ski lifts. Therefore, the exercise is not as efficient as the other modalities. In fact, the authors concluded that at least 2½ hours of alpine skiing are necessary to reach the same energy expenditure of an hour of cross-country skiing or cycling (Stöggl et al., 2016).

While alpine skiing may provide the basis for improvement in VO_{2max} in young people, it may be different in the elderly. In a study by Scheiber et al. (2009), this was investigated in nine healthy recreational alpine skiers, aged 62. Oxygen consumption of the skiers was measured continuously while skiing on two different slopes. Oxygen consumption is shown in figure 2 along with inserts of the relative exercise intensity. Regardless of time of day, slope, or skiing technique, the exercise intensity did not reach a level (>60%) at which a marked effect on cardiorespiratory fitness can be expected (Scheiber et al., 2009).

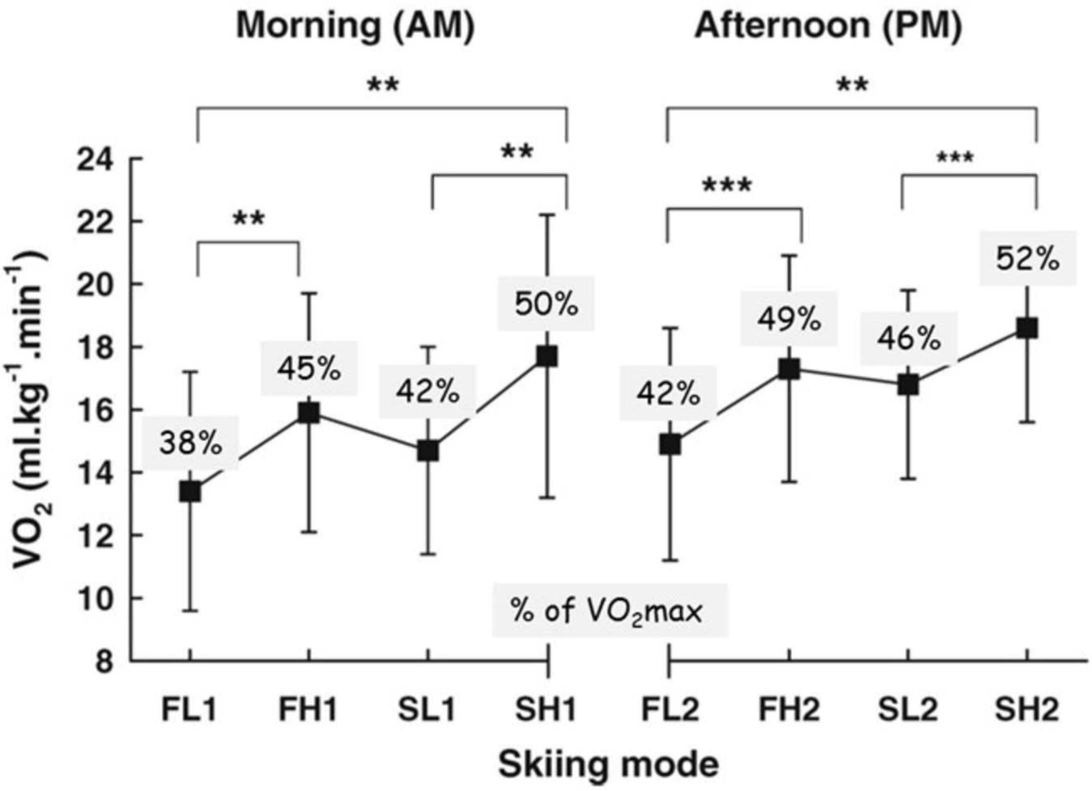

Figure 2 *Scheiber et al. (2009) measured oxygen uptake in nine healthy, elderly recreational alpine skiers in the morning and in the afternoon. The skiing modes were flat-low (FL) intensity, flat-high (FH) intensity, steep-low (SL) intensity, and steep-high (SH) intensity skiing.*

Skiing intervention studies in elderly

The Salzburg skiing study for the elderly (SASES) is an intervention study in which men and women in their mid-60s participated in a skiing program for 12 weeks, with instructed alpine ski training two or three times per week (Müller, Gimpl, Poetzelsberger, Finkenzeller, & Scheiber, 2011). Well-matched subjects served as a control group. VO_{2max} was measured before and after the intervention and again after three months (retention test). VO_{2max} increased significantly (by approximately 7%) with the intervention in the skiers, while no change was observed in the control group (Müller et al., 2011). In the retention phase, which took place 11 or 12 weeks after the end of the intervention, the skiers were able to maintain their aerobic capacity, while the control group showed a slightly greater decrease in VO_{2max}. However, even though the increase in VO_{2max} was significant from a statistical perspective, the individual data showed substantial variation (figure 3).

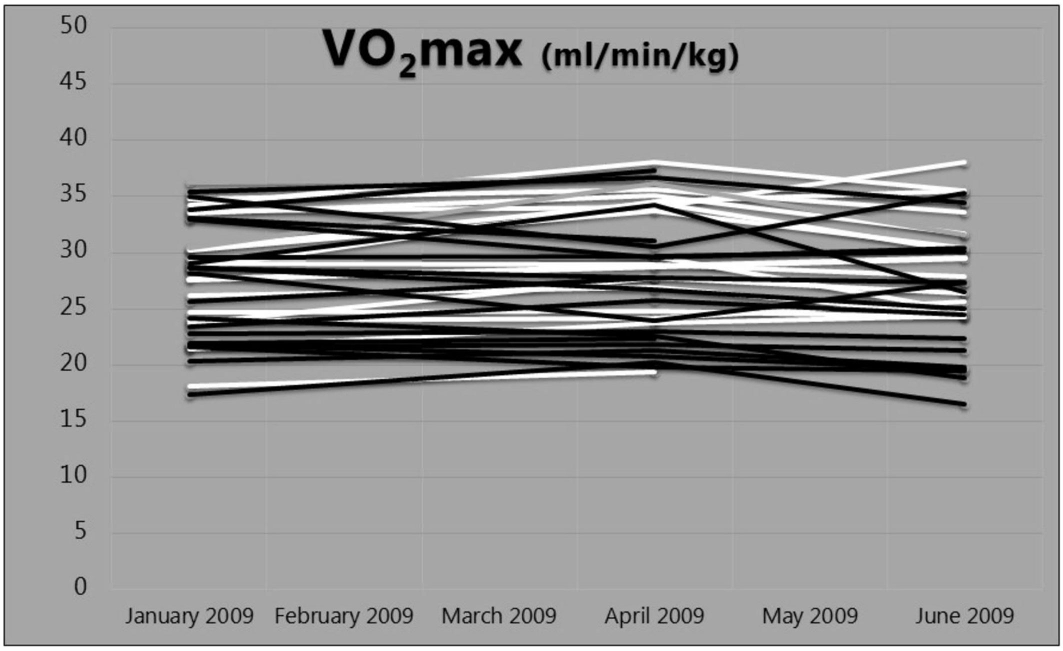

Figure 3 *VO_{2max} was measured before and after a skiing intervention and again after three months (retention test) in elderly skiers (white) and control subjects (black). VO_{2max} increased significantly (by approximately 7%) with the intervention in the skiers, while no change was observed in the control group (Müller et al., 2011).*

This is easier seen when individual changes to the intervention are plotted as in figure 4.

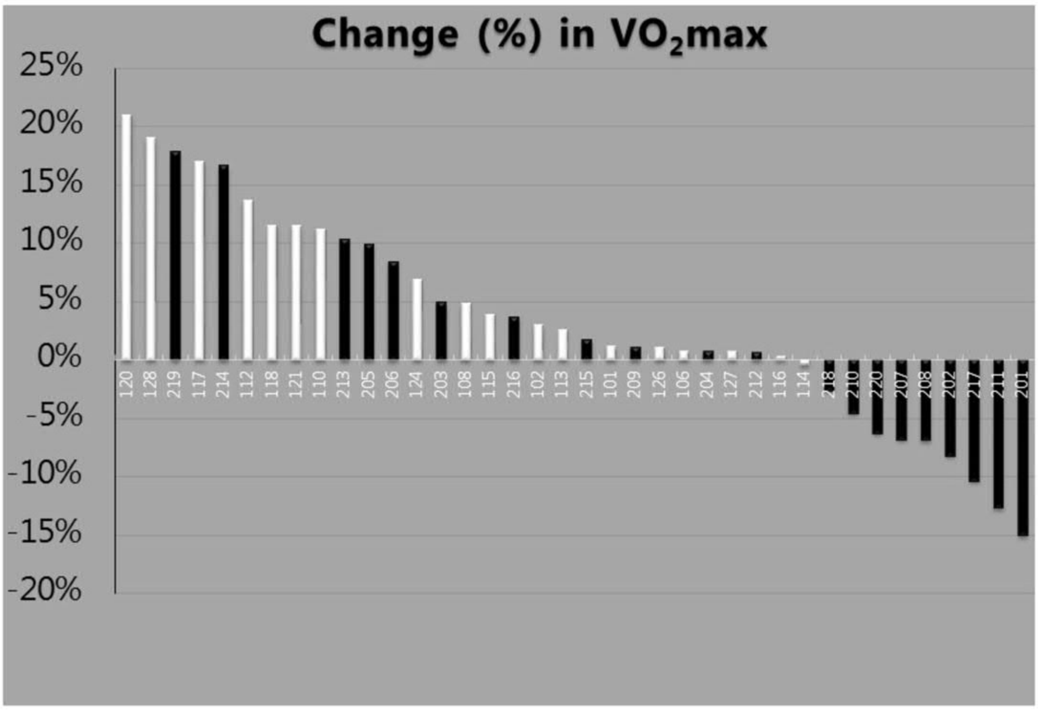

Figure 4 *Individual data (shown as a percentage of change in VO_{2max}) revealed a marked individual response in skiers (white) and control subjects (black). Data from Müller et al. (2011).*

The variation in response is remarkable, ranging from +21% to -0.4% in the skiers. The responses in the control group are also remarkable: although some subjects increased their VO_{2max}, the majority in fact decreased in VO_{2max}. All skiers were subject to a similar training program and adherence was high (Müller et al., 2011).

The variation in the response to the intervention is not unusual (Bouchard & Rankinen, 2001) and underlines the importance of focusing on individual data. A unique feature of the SASES study data is also the documentation of the variance in the control group (figure 4).

In this particular study, the control subjects' daily physical activity was not monitored, but instructions about maintenance of exercise habits were given. The magnitude of the individual changes in VO_{2max} is remarkable and not easily explained. The group mean change was 0 ± 9% (Müller et al., 2011) which again emphasizes the importance of studying individual data.

Summary of the cardiorespiratory response to alpine skiing

Recreational alpine skiing without constant supervision is probably not sufficient to improve VO_{2max}, but individuality is important! For group mean to improve, intensity should be >75% of VO_{2max}, which is difficult to achieve for longer time periods. However, there are many other positive effects of recreational alpine skiing, such as improved balance, muscle strength, muscle mass, and psychological benefits. This is particularly true for elderly people.

Effects of alpine skiing on metabolism

Daily physical activity is known to improve glucose homeostasis. In non-diabetic people, a decrease in fasting plasma concentrations of insulin (and C-peptide) is primarily seen following an exercise training program, while fasting plasma glucose concentrations typically do not change. The decrease in insulin is reflecting an improvement of (skeletal muscle) insulin sensitivity. Thus, less insulin is needed to facilitate glucose uptake in insulin sensitive tissues (skeletal muscle and adipose tissue). With alpine skiing, this adaptation is demonstrated in elderly, healthy people (Dela et al., 2011). However, as with the cardiorespiratory responses, large differences in the response are seen (figure 5).

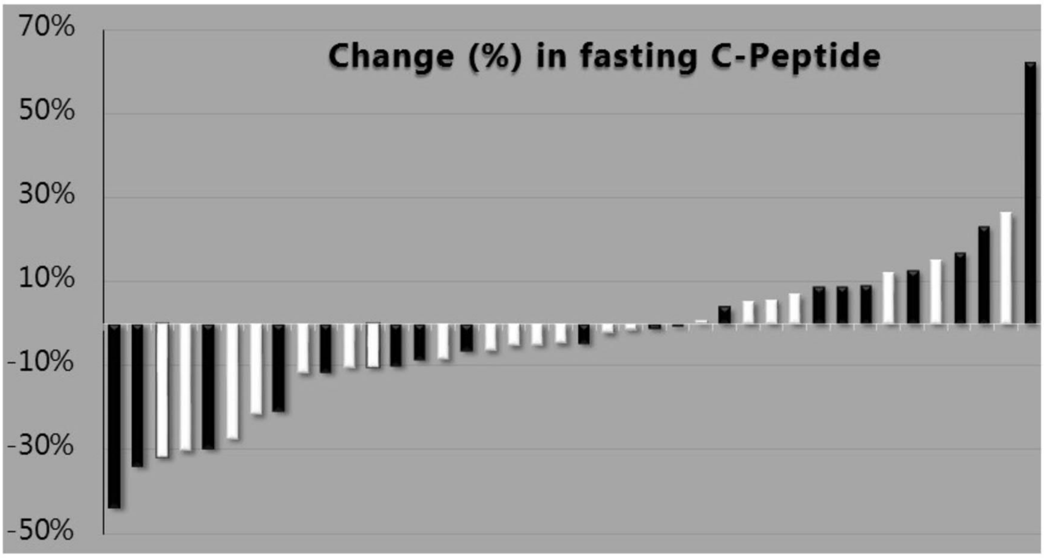

Figure 5 *Changes in fasting C-peptide (as an index of insulin resistance) concentrations in elderly skiers (white) and control subjects (black). Data from Müller et al. (2011).*

Identification of other phenotypical characteristics of those who decreased fasting C-peptide concentrations is necessary to predict who will benefit from such an intervention and who will not. However, no uniform pattern could be detected (Dela et al., 2011), leaving the question of responders versus non-responders unsolved. For this marker of glucose homeostasis, it remains clear that for many reasons the picture is more complex than for maximal oxygen uptake.

Insulin sensitivity can be estimated by the homeostasis model assessment (HOMA index). While this index is not better than fasting insulin alone, both parameters did in fact improve in the SASES study (Dela et al., 2011).

Of particular interest in elderly people is the question of whether alpine skiing may decrease cardiovascular risk factors, such as adiposity, blood lipids, and blood pressure. In the SASES study, total cholesterol, low-density lipoprotein, triglycerides, glycerol and (not statistically significant) free fatty acids decreased in response to alpine skiing during an entire season. However, a similar finding was seen in the non-skiing control group, raising the question of whether changing dietary habits from winter to spring may have an even greater influence. While body weight did not change, the skiers gained muscle mass (% body fat decreased) (Dela et al., 2011), which is a favorable change.

Summary of the metabolic response to alpine skiing

The overall conclusion is that alpine skiing may very well serve as a recreational physical activity which brings about improvements in glucose homeostasis, even though the dynamic component of the exercise intensity during alpine skiing is not high nor can it be sustained for longer periods of time. However, the strength training component of alpine skiing also contributes to muscular adaptations that are important for metabolic health.

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CONCENTRIC, ISOMETRIC, AND ECCENTRIC CONTRACTIONS: WHICH DOMINATES ALPINE SKIING?

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Keywords: alpine skiing, muscle contraction, energy dissipation

Introduction

To understand whether a motor activity involves more concentric, isometric, or eccentric muscle action is both a cultural advancement with classification benefits and a requisite for a better and more aware design of training sessions for amateur and professional athletes. That partitioning could also lead to a physiological prescription of exercise for special populations of active people. For example, muscle strength decays with aging less for eccentric than for concentric activity (Porter et al., 1997). Alpine skiing—with its potential eccentric dominance but a smaller impact than felt when running—could be a good choice for older people.

Before discussing the role of biological actuators and structures in managing the descent, let's start with physics, its rules, and its constraints. In all variations of alpine skiing, the skier's body (and equipment) is brought uphill by a motor-driven cable car. During this ascent, the potential energy (PE) of the body—which is equal to mass times gravity times altitude—increases because of the altitude gained. Just before the descent, the skier's kinetic energy (KE)—equal to half the mass times the speed squared—is zero because the speed is zero. At this point, several options are theoretically possible. A free fall in a vacuum would result in reaching the altitude from which we started at a very high speed, corresponding to completely transforming the extra PE gained into KE. This would also occur after a longer time if moving along a frictionless slope (and surrounded by vacuum). In both cases, we could say that total mechanical energy of the body has been conserved. An alpine skier starts and ends the downward track at a speed of zero, hence the entire gain in PE is lost as heat. This is energy dissipation and occurs because of a couple of actions.

All of them result in negative work, defined as the work done by a force when its point of application moves toward—versus opposite to—the one of the force. Air drag, ski-snow friction, material deformation, and eccentric muscle force act on their points of application by partially resisting the imposed movement and slowing it down. Within the deformable material, there are skiis (particularly with pronounced carve and camber), track gates (during competitions), and biological tissue such as ligaments, tendons, and bones, which suffer some elastic histeresis and immediately transform part of the deformation energy into heat.

Alpine skiing is a matter of controlling the energy dissipation through the proper management of ski-snow friction and of the trajectory constraints imposed by the uneven and curved terrain.

Although not fundamentally relevant, we must mention the chances of energy production during the descent. Some of the elastic energy stored in the deformed skiis and tendons because of the ground force reacting to the centripetal force during the turn could be released, contributing to an increase of the total energy of the body. This could also occur as an effect of muscle concentric contraction, an effect still to be demonstrated (particularly regarding racers).

In synthesis, the difference between a recreational and a competitive alpine skier is that the former does his or her best to keep a safe speed by gradually managing the transformation of extra PE into KE, while the latter has the aim of converting most PE into KE—and thus speed—for the imposed trajectory, possibly by adding some extra mechanical energy. Their speed—already penalized by having hit the gates (additional negative work)—has to be maximized, and nobody cares about the risk of crashing after the finish line.

The knowledge of the partitioning among eccentric, concentric, and even isometric muscle activity (i.e., when the muscle end points do not move while force is produced) is particularly relevant for designing training regimes and setting the fitness requirements for alpine skiers. Also, despite the multitude of muscle enhancement strategies available nowadays, an athlete's training time has to be very specifically tailored according to individual and sport-related specifications.

Now that the main actors in energy dissipation have been listed—but before dealing with what muscles really do—a question could be posed about the existence of a mode of descent that would just be affected by air drag and ski-snow friction (with no muscles involved). We all remember how we started skiing by practicing the snowplow, (Stem-Christiania or Spazzaneve, invented by Hannes Schneider in St.

Anton, Arlberg, in 1910) consisting of a fixed posture with V-shaped skiis throughout the whole (almost straight) descent. That strategy mainly involves using the plow effect to move snow sideways and generate an opposing reaction force that decreases the total body energy through ski-snow friction (air drag is negligible at that speed). Although a similar passive machine could be constructed, in our biological example some muscle action is required, mainly in the form of isometric activity devoted to making our body a rigid structure that advances as one rigid block with no other degree of freedom.

The above argument can be easily rejected by the observation that snowplowing is not real skiing. But in 1968, Helmut Gottschlich and Hans Zehetmayer of the Institut für Sportwissenshaften, University of Wien, invented a passive model capable of closely reproducing slalom (https://www.youtube.com/watch?v=cfEzIcFTq_o, starting at 9:40) just by transforming PE into KE, which was kept almost constant by a realistic ski material interaction. The main message from that model is that skiing is feasible without any muscle intervention, apart from some isometric contraction needed to stiffen our musculoskeletal system. Thus the inferior limit of the biologically added negative work is zero (we need to remember that isometric contraction, though metabolically expensive, corresponds to zero work because there is no distance travelled by the point of application of the force).

However, even from visual inspection of video footage, it emerges that both recreational and competitive alpine skiing incorporate phases (e.g., during turns and landing after jumps) where hip and knee joints are clearly flexed or extended, demonstrating muscle actions different from just isometric contraction. Also, though there is no comparison with the pain experienced by downhill runners, muscle damage deriving from eccentric, negative work often results in some delay onset muscle soreness (DOMS) in the early part of the ski season, witnessing the potential presence of intense eccentric activity.

Within the whole variety of alpine skiing, only downhill skiing, with its frequent jumps and landings, exposes the body to sudden vertical decelerations, after which the control of the trajectory has to be promptly reestablished. In the laboratory, such high-impact negative work and power has been studied by letting subjects drop from a given height and asking them to land in the shortest possible time (Minetti et al., 1998; Minetti et al., 2010). In the other specialties of alpine skiing (i.e., slalom, giant slalom, Super-G, mogul, and freestyle), most of the negative work is expected to occur in the middle of each turn.

But isometric and concentric contractions are also expected, as most of the joints undertake cycles of extension-flexion movements. The real challenge is not just describing the effects of alpine skiing on joint kinematics, but approaching the kinetics of skiing affecting the prevalence, in energetic terms, of each of the three muscle contraction type.

To understand how much of the cumulated potential energy has to be dissipated by muscles, we first have to establish which part is dissipated by other forces. Air drag, despite the continuously changing frontal area of the skier, can be modeled after average anthropometric values. Ski-snow friction, however, is very difficult to estimate. It depends on snow granularity, temperature, and humidity, but the complexity stays in the modality at which it occurs. As opposed to a simple ski travelling flat on a constant gradient slope (which is quite simple to model), a skier's actions in terms of turn radius, speed, lean angle, maximum slope angle, ski cut angle on the snow, and presence of skidding can greatly affect friction and make modeling a nightmare. For a given descent, most of those parameters can be experimentally measured with different devices and methodologies. High-frequency GPS with barometric altitude, high-resolution geological maps of the relevant area (ArcGIS files), and inertial measurement units (IMUs) with gyroscopes and magnetometers can provide the necessary data, but their accuracy and precision—still to reach a technological asymptote—are crucial for reaching a more complete picture of skiing dynamics.

Using GPS and barometric data and 3D terrain mapping, a recent experiment of ours in Valtournenche Ski Resort (Val D'Aosta, Italy) estimated that at least 40-50% of PE is dissipated by air and snow friction (ground reaction force and lean angle were estimated, although no skidding was assumed), leaving the remaining part to eccentric muscle activity. This estimate should be taken with caution, as it depends on snow condition and the downhill track shape and slope (in our experiment, it was a giant slalom simulation). For these reasons, the fraction of the total negative work attributable to muscle can also vary with the alpine skiing specialty considered.

In addition, when the time course of net total body energy (PE + KE - air - snow) during the descent is drawn, some unexpected positive glitches appear, suggesting that the total energy is not subjected to the unavoidable destiny of a monotonic decrease (dissipation) in alpine skiing. Somewhere in the descent, total energy can be (very temporarily) increased, and a potential candidate is (again) muscle, with a concentric activity probably following a previous tendon stretch, as caused by the ground reaction force opposing the centripetal force of the turn. This effect could be ascribed to the concept of power amplification (Minetti and Susta, 2010). Another option is that tendon elastic release occurs while extensor muscles are in isometric activity.

A final word about the muscle use during downhill skiing: EMG measurements and knee and hip electrogoniometry seem to be unavoidable procedures. For some of the most important joint extensor or flexor muscles, experimental protocols exist to obtain a correlation between the measured activity and the isometric force and torque generated at that muscle length or joint angle. Electrogoniometry can also tell whether a joint is flexing or extending, or has no angle change, allowing us to infer during downhill turns which activity is predominant. Together with EMG measurements, it can tell (within an angle change that must add up to zero) at which joint operative angle range most of the eccentric, isometric, and concentric muscle action takes place. We can also expect activation strategies devoted to stiffening the joints, even when they are not keeping a constant angle. To study the synergy among muscle groups, the statistical cross-correlation analysis helps to reveal time courses of EMG patterns that act similarly, despite the differences in absolute activity levels.

While analyzing EMG activity of nine muscles on a single side (the right leg) of the body during the quoted experiments, we noted that some synergies between groups that are present or absent when turning left become absent or present when turning right. Such analysis, seen as the ability to distinguish what happens to the internal and the external leg when performing a turn on the same side, can also reveal the skier’s ability to equally partition the turn control on both legs.

Results

From our preliminary results of electrogoniometry, we have the impression that a prolonged isometric phase (remember the mechanical model above) is an infrequent occurrence, although the same experiments on different ski specialties could alter this suggestion. Thus the remaining 50% of cumulated potential energy (in slalom-like tracks) is likely to be dissipated by negative muscle work or by a net negative work resulting from a dynamic stiffening of joints as caused by co-contracting antagonist muscles.

In the past, similar approaches to the mechanical energy balance problem in alpine skiing have been brought forward (Berg et al., 1995; Kugovnik and Nemec, 2012; Reid et al., 2012; Meyer and Borrani, 2012), including attempts to elucidate the intimate changes of skiing mechanics as affected by training and material evolution (Kröll et al., 2014). Still, a comprehensive picture of the prevalent muscle activity in the different ski specialties is lacking.

It is crucial to realize that at this point in instrumentation technology, the illustrated parameters still strongly depend on measurement resolution, accuracy, and precision. Although the calculated body lean angle, when synchronized with the video footage, closely follows the skier's posture turn after turn, the result is a combination of very heterogeneous signals: GPS horizontal and vertical coordinates are sampled at 10Hz, while the vertical one (barometric) at just 1Hz; and the spatial resolution is sub-meter while the ArcGIS files reporting the altimetric profile of the terrain surrounding the ski track is a grid made by nodes at 10m distances.

Discussion

In summary, alpine ski mechanics, the understanding of which would allow us to predict muscle use, indicate zero as the lowest limit of extra negative work. Despite the environmental, experimental, and technical complexity of this motor activity, modern GPS, hi-res cartography, EMG and electrogoniometry, wireless loggers and drone technology allow a more accurate description of it. An energy analysis of descents on skis seems to indicate that less than 40-50% of the potential energy has to be dissipated by muscles via eccentric contractions. Measurement improvements in the next few years will allow us to evidence any positive work (concentric) contributing to increase a skier's kinetic energy at the end of a turn.

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