ANALYSIS OF COMBINED EMG AND JOINT ANGULAR VELOCITY FOR THE EVALUATION OF ECCENTRIC/CONCENTRIC CONTRACTION IN SKIING

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The purpose of this study was the introduction of a method combining the joint angular velocity and the EMG signals for a biomechanical evaluation of the eccentric/concentric contraction patterns of major muscles used in alpine skiing. The adopted approach was applied to three types of slalom courses: racing, training and recreational slaloms. The introduction of a pseudo-Muscular-Work allowed to define a Ratio between Eccentric and Concentric muscular activation states that, compared to simple on-off timing criteria, resulted to reveal more consistently the amount of eccentric muscle mechanical work.

KEY WORDS: joint angular velocity, EMG, eccentric, concentric, index.

INTRODUCTION: In alpine skiing, the knowledge of the type and intensity of muscle contraction during racing or recreational skiing events is able to give important information about the skiing technique, the effect of equipment tuning and the proper training program and exercise definition. Several authors have studied muscle contraction patterns in alpine skiing: Tesch (1995) described the physiological demands in competitive alpine skiing and the physiological profile of elite skiers, Berg et al. (1999) studied concentric and eccentric muscle use in relation to positions and angular movement velocities of the hip and knee joints, Hintermeister et al. (1995) investigated muscle activity in slalom and giant slalom finding a similarity in muscle activation between the two disciplines with ample evidence of co-contraction suggesting a quasistatic component to skiing. Hoppeler et al. (2009) defined a method for applying an eccentric ergometer suitable for evaluating and training the eccentric activation of anti-gravitational muscles. Considering these previous investigations and the variables analyzed we decided to develop a method suitable for quantifying eccentric and concentric muscle contractions actions. This analysis was applied in two skiing sessions to three types of courses, namely racing slalom, training slalom and free field recreational slalom.

METHODS: Data Collection: Two test sessions were performed to study three different skiing conditions with the same tester. In Session1, a training slalom on a medium steep slope and a free-field recreational slalom were recorded; in Session2, a racing slalom on a steep, icy snow was recorded. Data of each course were recorded by means of a 16 channels PDA PocketEMG (BTS-Italy) placed on the chest of the skier (145x95x20mm, mass 0.3kg). In Session1, eight channels were used to collect EMG data of the right leg and the back of the subject (inter-electrode distance 25mm). Muscles analyzed were: Erector Spinae, Gluteus Maximum, Vastus Lateralis, Vastus Medialis, Biceps Femoris, Semimembranosus, Tibialis Anterior and Gastrocnemius Medialis. Two Biometrics goniometers were laterally placed at the right knee and right hip. Four more channels were employed for the acquisition of two strain gauged accelerometers stuck on the shin guards. In Session2, the eight EMG channels were symmetrically placed at the two sides of the tester: Vastus Medialis, Biceps Femoris, Tibialis Anterior and Gastrocnemius Medialis were recorded. The two Biometrics goniometers were placed on both knees and all data were synchronously recorded at 1Khz.

A professional ski tester was involved in the study. Before the tests he was asked to read and sign an informed consent. In Session1, ten short poles were placed in the snow (span 4 m, pace 12 m, named S0-S9 with odd numbers external turns for right leg) along a medium steep slope. Two additional poles at a span of 60 m were employed to mark the free slalom area. In Session2, 26 short poles were placed in the snow (*span 4 m, pace 12 m*, named S0-

S25 with odd numbers external turns for right leg) along a steep slope.

Data Analysis: Analysis of courses between poles was based on the identification of impact instants of the leg with the pole shown by the shin guard accelerometers, in such a way that internal/external turns of each leg could be easily identified. EMG raw signals of the recorded muscles were rectified, integrated with a mobile window of 200ms and filtered with a 5Hz low pass 3rd order Butterworth filter.

Aim of the work was the definition of a method for muscle eccentric/concentric contraction analysis including not only the sign of the angular velocity, but also the instantaneous level of muscle activation that is experimentally expressed by an integrated iEMG signal. To quantify knee flexor and extensor muscle activity and to relate them to the knee joint angular velocity, data were therefore analyzed as follows.

The relative angle between thigh and shank axes (θ) was set at 180° with knee fully extended and its time derivative, the angular velocity (ω) of the knee joint, was coherently assumed positive during extension and negative during flexion. Assuming that the muscle Activation signal (iEMG) is correlated to the Force exerted at the muscle insertion, and that the force multiplied by the tendon lever arm is in turn producing the muscle Torque applied to the joint, then the angular velocity (after low pass filtering at 5Hz) was multiplied by the integrated EMG signal (iEMG) of flexors muscles (Biceps Femoris and Semimembranosus) and extensors muscles (Vastus Medialis and Vastus Lateralis) to obtain a new set of curves: the product between Activation (iEMG) and joint angular velocity (ω) was named *pseudo Muscular Power* (pMP). The "pseudo" prefix is due to the complex relationship between Activation and Force, the nonlinear variation of the tendon Lever arm with the Joint relative angle (θ) and the motion at other proximal/distal joints (like the hip or the ankle) in the case of bi-articular muscles. Nevertheless, the *pseudo Muscular Power* (pMP) was supposed to be possibly adopted as a meaningful parameter to discriminate eccentric and concentric muscle actions from a mechanical point of view.

Coherently with the angular convention, the muscle knee Torque contribution was set positive if acting in extension, both for extensor and flexor muscles: therefore the pMP resulting curves showed positive parts corresponding to concentric contractions and negative parts for eccentric contractions for all the muscles. Subsequently, the area enclosed between the positive part of the pMP curve and the time axis, calculated after integration versus time on a pre-defined time period, was associated with a *concentric pseudo Muscular Work* (pMW_C); conversely the area enclosed between the negative part of the pMP curve and the time axis was associated with an *eccentric pseudo Muscular Work* (pMW_E). Finally the ratio R_{MWEC} between pMW_E and pMW_C was introduced as an immediate index useful to estimate in a certain interval of time the relative amount of eccentric and concentric muscular work.

A different method for evaluating the eccentric/concentric contraction amount, based on the simple analysis of the sign of angular velocity, was applied to find how much time the muscle spent in a concentric or eccentric phase during a given time period. Looking at the angular velocity sign (positive for concentric, negative for eccentric contraction), the ratio R_{TEC} of eccentric and concentric contraction intervals was calculated. Both the two indexes R_{MWEC} and R_{TEC} were calculated for Session 1 over the interval between S2 and S7 poles as well as over the whole 60 m free slalom duration for each course; for Session2 the indexes were calculated from the 5th to the 15th pole.

RESULTS: Knee relative angle (θ), angular velocity (ω), pseudo muscular concentric and eccentric power (pMP_C and pMP_E) of each muscle were calculated for the whole 60 m free slalom, then for the training slalom in the interval between S2 and S7 poles, and finally between S5 and S15 poles for the racing slalom as reported in Figure 1 for vasti muscles as an example.

In Table 1 the values of R_{MWEC} and R_{TEC} are presented for the three types of slalom for direct comparison.

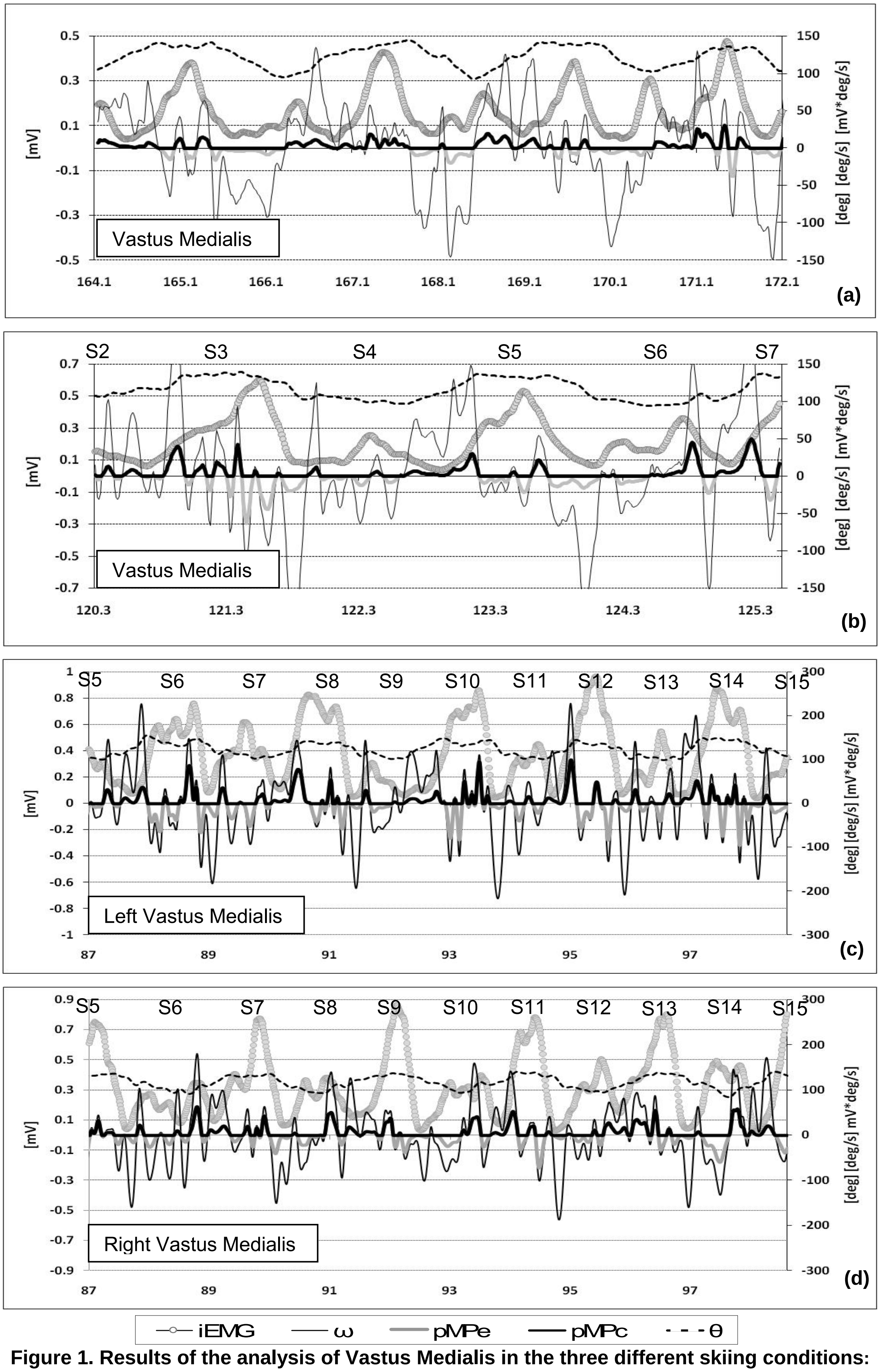

Figure 1. Results of the analysis of Vastus Medialis in the three different skiing conditions:
(a) free slalom, (b) training slalom, (c & d) racing slalom.

Table 1 R_{TEC} versus R_{MWEC} for eccentric and concentric muscle evaluation in the three skiing conditions.

60 m FREE SLALOM	TIME = 7.52 sec	
	R_{MWEC}	R_{TEC}
Vastus Medialis	1.07	1.08
Vastus Lateralis	1.06	
Biceps Femoris	0.93	0.93
Semimembranosus	0.57	
TRAINING SLALOM	**TIME = 5.12 sec**	
	R_{MWEC}	R_{TEC}
Vastus Medialis	0.66	0.78
Vastus Lateralis	0.57	
Biceps Femoris	1.85	1.28
Semimembranosus	1.03	
RACING SLALOM	**TIME = 11.50 sec**	
	R_{MWEC}	R_{TEC}
Left Vastus Medialis	1.07	0.96
Right Vastus Medialis	0.95	1.06
Left Biceps Femoris	1.25	1.04
Right Biceps Femoris	1.23	0.95

DISCUSSION: The ratio between eccentric and concentric knee muscles action elaborated with the two methods showed appreciable differences. The ratio between eccentric and concentric contraction calculated in terms of time duration using angular velocity (R_{TEC}) showed similar values for both flexors and extensors in the free slalom with a minimal predominance of the eccentric action. In training slalom there is a great eccentric contraction of flexors muscles and concentric contraction of extensor muscles. Finally in racing slalom the eccentric and concentric knee muscle actions were very close. R_{MWEC} allowed to appreciate an increase of the eccentric action of the biceps femoris in training and racing slalom and this result may have relevance for proper training and injury prevention.

The introduction of concentric and eccentric pseudo Muscular Work (pMW_C and pMW_E) was useful to better understand the intensity of the eccentric and concentric activation. In fact, eccentric and concentric contraction calculated in terms of time duration using only the sign of angular velocity missed important functional information: how hard muscle fibres were working in that condition. The consequence is that a muscle which spent short times in eccentric action with a high activation shouldn't be trained as a muscle which spent for example short times eccentrically but with a low level of activation.

CONCLUSION: A marked predominance of eccentric over concentric muscle actions was not observed in the quadriceps muscles. The evaluation of concentric and eccentric muscle action during three types of slalom can give important information for athletes and trainers in the development of specific training programs in term of intensity of the stimulus, time duration and knee angular velocity. Further investigations with a higher number of professional skiers and with a higher number of courses could help to better understand knee flexors and extensors eccentric and concentric actions with respect to time and intensity of activation.

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