Original Article

P. Zamparo · G. Antonutto · C. Capelli
P. E. di Prampero

Effects of different after-loads and knee angles on maximal explosive power of the lower limbs in humans

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Abstract Maximal explosive power during two-leg jumps was measured on four sedentary subjects [mean age 43.0 (SD 10.3) years, mean height 1.74 (SD 0.04) m, mean body mass 73.5 (SD 1.3) kg] using a sledge apparatus with which both force and speed could be directly measured. Different after-loads were obtained by positioning the sledge at five different angles (SA, \(\alpha\)) in respect to the horizontal so that \(m \cdot g \cdot \sin \alpha\) (where \(m\) is the sum of body mass and the mass of the sledge seat, \(g\) the acceleration due to gravity) decreased (on average) from 78% body mass at 30° to 27% body mass at 10°, thus simulating conditions of low gravity. The subjects were asked to jump maximally, without counter movement, starting from 70°, 90°, 110°, and 140° of knee angle (KA); the protocol being repeated at 10°, 15°, 20°, 25° and 30° SA. The average \(W_{\text{mean}}^{+}\) power output during concentric exercise (CE) was found to decrease when the starting KA was increased, but to be unaffected by SA (i.e. by the after-load, the simulated low \(g\)). The higher values of \(W_{\text{mean}}^{+}\) were recorded at 90° KA [15.01 (SD 1.46) W · kg\(^{-1}\), average for all subjects at all SA]. The subjects were also asked to perform counter movement (CMJ) and rebound jumps (RE) at the same SA as for CE. In CMJ and RE, the maximal power outputs were also found to be unaffected by the SA; \(W_{\text{mean}}^{+}\) amounted to 16.03 (SD 0.28) W · kg\(^{-1}\) in CMJ and 16.88 (SD 0.36) W · kg\(^{-1}\) in RE (average for all subjects at all SA). In CE, CMJ and RE, the instantaneous force at the onset of the positive speed phase \(F_t\) was found to increase linearly with SA (i.e. with increasing \(m \cdot g \cdot \sin \alpha\)), and the difference between \(F_t\) in CMJ or RE and \(F_t\) in CE \((F_t\) in CMJ minus \(F_t\) in CE and \(F_t\) in RE minus \(F_t\) in CE) was unaffected by SA. This indicated that both maximal power and the elastic recoil were unaffected by simulated low \(g\) ranging from 1.71 m · s\(^{-2}\) (at 10° SA) to 4.91 m · s\(^{-2}\) (at 30° SA).

Key words Concentric exercise · Counter movement jumps · Elastic recoil · Simulated low gravity

Introduction

The power developed during a muscle contraction of very short duration, such as an upwards jump using both feet on a force platform, results from the transformation of chemical energy into mechanical work by the contractile elements of the muscle. It has been shown that in certain conditions, however, elastic energy can be temporarily stored in the series elastic, as well as in the contractile, components of the active muscle and released immediately after, thus contributing to the performance of external work (Cavagna et al. 1968). This has been shown to be the case in the stretch-shortening cycle exercise, in which part of the eccentric work performed on the muscles during the flexion is stored as elastic energy in the stretched contracted extensor muscles of the lower limbs and is used during the subsequent extension phase for the performance of positive work (e.g. Thys et al. 1972; Asmussen and Bonde Petersen 1974; Komi and Bosco 1978).

The aim of this study was to investigate the effects of different after-loads on the development of power in concentric, counter movement and rebound jumps. This was achieved by asking the subjects to jump on a sledge apparatus (the Multipurpose Ergo Dynamometer, MED) at different sledge angles (SA, \(\alpha\)) of 10°, 15°, 20°, 25° and 30° in respect to the horizontal so that \(g \cdot \sin \alpha\) ranged from 1.71 m · s\(^{-2}\) (at 10°) to 4.91 m · s\(^{-2}\) (at 30°). Therefore the after-load \((m \cdot g \cdot \sin \alpha)\) on the leg extensor muscles was lower than the subject’s body mass: it ranged from 196 N to 564 N (at 10° and 30° SA, respectively).

Therefore, since \(m\) was the sum of the subjects body mass [mean 73.5 (SD1.3) kg] plus the mass of the carriage
seat (41.4 kg), the after-loads used in this study ranged from 27% to 78% of subjects body mass on the average. For the 15° SA, the after-loads were close to the gravity condition prevailing on Mars where the body mass would be three eighths of that on earth. This reduction of the after-load, through the inclination of the sledge, simulated to a certain extent a reduction of gravity. The effects of simulated low gravity on maximal explosive power in humans will therefore also be discussed.

Methods

MED system

The MED (see Fig. 1) has been described in detail in previous papers to which the reader is referred (Antonutto et al. 1995; Zamparo et al. 1997). Briefly, the subject sat on a carriage seat which was free to move on two rails fixed to the main frame of the MED. A hydraulic system allowed the main frame to be inclined, up to a maximum of 30°, in respect to the horizontal. Two dynamometer platforms were positioned in front of the carriage seat (perpendicularly to the main frame) so that the subject, pushing with one or both feet on them, could accelerate himself and the carriage backwards. The forces exerted on the platforms were monitored by indwelling load cells (PA40 300, LAUMAS, Italy) and the backward speed of the carriage was measured using a wire tachometer (WT) (PT8201, CELESCO, USA) mounted on the back of the main frame and connected to the carriage seat. The analogue outputs of the force and velocity transducers, were recorded using a data acquisition system (MP 100 BIOPAC, USA) and further analysed using dedicated software (AcqKnowledge 3.0, Biopac Systems Inc., USA).

Subjects

The experiments were performed on four sedentary subjects (three men and one woman) of 73.5 (SD 1.3) kg mean body mass, 1.74 (SD 0.04) m mean body height, and 43.5 (SD 10.3) years mean age; they were informed about the aims of the study and gave their informed consent.

Fig. 1 Diagram of the Multipurpose Ergo Dynamometer. CS Carriage seat, DP dynamometer platforms, WT wire tachometer, HP hydraulic pump, MB mechanical blocks, W power

Experiment protocol

Concentric exercise

Two adjustable blocks were positioned on the rails of the MED (between the carriage seat and the platforms) thus: preventing the downward movement of the carriage seat, and allowing us to fix the starting position of the subject’s knee angle (KA). During these experiments, a mechanical system prevented the carriage from dropping against the platforms immediately after the maximal distance along the rails was reached and the direction of motion reversed.

The subjects were positioned on the carriage seat of the MED with their arms on the handle bar and the soles of their feet against the platforms. They were asked to perform a series of four maximal jumps at each of the following starting KA: 70°, 90°, 110°, and 140° (randomly selected and performed with at least 60 s between them). They then repeated the entire protocol at each of the following SA: 10°, 15°, 20°, 25° and 30° (see Fig. 2a).

Counter movement jumps

To allow the subjects to perform countermovement jumps (CMJ), the blocks in front of the carriage seat were removed, so that the carriage seat was free to move in both directions (i.e. also toward the platforms). The subjects, positioned on the carriage seat of the MED as before, were requested to perform, immediately before the concentric phase of the jump, a preparatory counter movement by bending the knees towards the platform from a starting KA of 180°. This exercise could be compared to the CMJ on a horizontal force platform in which the jump is started from an erect posture, as has been described by Bosco and Komi (1979) (see Fig. 2b).

Rebound exercises

Starting from the same position as in CMJ, the subjects were asked to perform a sequence of three jumps in quick succession. Of the three jumps, the first two were preparatory to the third (the rebound exercise, RE) which was the only maximal one. The data reported in this study refer to the third jump only. This exercise could be compared to the RE performed on a horizontal force platform that has been described by Thys et al. (1972) (see Fig. 2c).

In both CMJ and RE the subjects were free to choose the amplitude of the counter movement, i.e. to choose the KA from which to start the following (concentric) phase of the jump. The subjects repeated the CMJ and RE protocols at each SA (10°, 15°, 20°, 25°, 30°).

Each subject was asked to repeat each of these jumps four times at each SA; one subject did not perform the experiments at 30° SA. Hence, the number of observations in CMJ and RE was 16 (4 subjects times 4 jumps) at 10°, 15°, 20° and 25° SA and 12 (3 subjects times 4 jumps) at 30° SA (total n = 76). During CE the subjects were requested to repeat, at each SA, the experiments at 4 different KA. Hence, the number of observations in CE was 64 (4 subjects times 4 jumps times 4 KA) at 10°, 15°, 20° and 25° SA and 48 (3 subjects times 4 jumps times 4 KA) at 30° SA (total n = 304). During the processing of the data a few jumps were discarded for technical reasons. Hence, the total number of observations was n = 294 in CE, n = 72 in CMJ and n = 75 in RE.

The order of the experiments was randomly selected in separate sessions during a week to avoid fatigue.

The five selected SA corresponded to the following percentages of body mass (m): 27% at 10°, 40% at 15°, 53% at 20°, 66% at 25° and 78% at 30° SA.

Data processing

Typical traces of force (sum of the two legs), velocity and power during a maximal all-out effort are reported in Fig. 2a (CE), 2b