Comparison of Level and Stair Walking

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Introduction

Stair climbing can be a quite demanding movement task when motor functions are reduced, for example in elderly or obese subjects, women during pregnancy, and subjects with musculoskeletal diseases. The analysis of biomechanical and motor control aspects involved in stair climbing can add to our understanding of the diverse and complicated processes involved in human locomotion. Furthermore, it can be useful in the design of private and public environments where stairs are employed. Another application is in the field of gait rehabilitation where a comprehensive movement analysis of stair climbing can support the evaluation of joint replacement or the development of exo-/neuro-prostheses.

Several studies were performed to investigate normal human stair ascent and descent (Andriacchi et al., 1980; McFadyen and Winter 1988; Kowalk et al., 1996). However, no comprehensive analysis is available in the literature that discusses biomechanics of stair ascent and descent at different inclinations, although stair inclination proves to be an important parameter for the comparison of joint kinematics and muscle activity at varying step heights (Müller et al., 1998). Our study is an attempt to face the question of how staircase inclination affects the kinematic and kinetic patterns of stair climbing, and to ascertain if ascent and descent patterns are to be considered as particular evolution of the level walking pattern.

Fig. 1: Experimental setup.

Methods: Experimental Setup and Protocol

A staircase was developed that allowed the collection of kinetic data for multiple steps at different staircase inclinations between 24.0° and 42.0° (Riener et al., 1999). The lower three of the four steps (Fig. 1) were instrumented with strain-gauge force transducers that enabled the recording of the 3D ground reaction force, the vertical component of the ground reaction moment, and the location of the center of
pressure (COP). An optoelectronic system (ELITE) recorded the spatial positions of passive markers attached to both legs at the foot, ankle, knee, hip, and pelvis.

Ten healthy male subjects of similar stature and age (24 to 34 years) ascended and descended the stairs at 3 different inclinations (24°, 30°, 42°). Kinetic and kinematic data were processed for the middle strides of the staircase. Internal anatomical landmarks and joint centres were estimated from the external marker positions by an optimisation procedure in which anthropometry and joint kinematics were taken into account (Frigo et al., 1998). A Newton-Euler based inverse dynamics approach was applied to compute joint moments and powers (Rienert und Straube, 1997).

For comparison with level walking, data from 26 normal subjects were available from the data bank of the Centro di Bioingegneria gait laboratory, which were elaborated by a similar protocol as the present one (Frigo et al., 1998).

**Results**

The different kinematic and kinetic patterns of stair ascent and descent were analysed and compared to level walking patterns (Fig. 2). Temporal gait parameters (cycle and stance duration), ground reaction forces, and COP path were not significantly affected by staircase inclination. Joint angles and moments showed a relatively low but significant dependency on the inclination. A larger influence was observed in joint powers. In the most joints the range of angle, moment, and power increased with increasing inclination of the staircase during both ascent and descent.

The kinematic and kinetic patterns of staircase walking differed considerably from level walking (Fig. 2). The main characteristics were:
• All subjects contacted the step with the forefoot, in all staircase inclinations during ascent and descent.
• The joint angle ranges were generally larger during stair walking than during level walking.
• The COP path was limited to approximately 10 cm in the metatarsal area and typically characterised by an early backward progression followed by a forward progression.
• During descent the extension moment at the knee was up to 2.8 times greater and the maximum power absorption at the knee was up to 3.5 times greater than during level walking.

The ranges of moments and powers in the hip and ankle joints were comparable in stair and level walking. Ground reaction force patterns during ascent and descent preserved most of the features observed during level walking.

Discussion and Conclusion
Although there was a significant dependency of most gait parameters on staircase inclination, the intensity was different. For example, there was only a little to moderate influence of the inclination angle on gait kinematics, i.e. joint angles, and joint moment patterns. Angular ranges of all joints increased with increasing inclination angles. This is consistent with the need for a higher elevation of the foot at increased step heights.

The largest differences were observed in the joint power patterns. Joint powers in the hip and ankle changed up to approximately 60% when increasing the inclination from the minimum to the maximum value. This change is required to surmount the increasing potential energy during stair climbing.

One can expect that the kinematic and kinetic data of level walking lays somewhere between the data of ascent and descent. However, it was observed that most of the patterns and parameters did not change in a progressive way, when comparing descent at decreasing inclinations (-42°, -30°, and -24°), level walking, and ascent at increasing inclinations (24°, 30°, and 42°). For example, differences in the climbing data between minimum and maximum inclination (24° and 42°, respectively) were remarkably smaller than the differences between level and stair walking.

This leads to the assumption that there is a certain inclination angle or angular range, where the subjects switch their gait patterns and, thus, their motor control strategy between level and stair walking. This change must occur at an inclination angle below 24°, and might be related to the condition at which initial foot placement switches from heel contact to forefoot contact. This may affect gait kinematics and dynamics. Further studies are necessary to confirm this hypothesis and detect the inclination at which this switch between gait patterns takes place.

References