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Mechanical energy assessment of adult with Down syndrome during walking with obstacle avoidance

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ABSTRACT

The aim of this study is analyzing the differences between plane walking and stepping over an obstacle for two groups of healthy people and people with Down syndrome and then, evaluating the movement efficiency between the groups by comprising of their mechanical energy exchanges. 39 adults including two groups of 21 people with Down syndrome (age: 21.6 ± 7 years) and 18 healthy people (age: 25.1 ± 2.4 years) participated in this research. The test has been done in two conditions, first in plane walking and second in walking with an obstacle (10% of the subject's height). The gait data were acquired using quantitative movement analysis, composed of an optoelectronic system (Elite2002, BTS) with eight infrared cameras. Mechanical energy exchanges are computed by dedicated software and finally the data including spatiotemporal parameters, mechanical energy parameters and energy recovery of gait cycle are analyzed by statistical software to find significant differences. Regards to spatiotemporal parameters velocity and step length are lower in people with Down syndrome. Mechanical energy parameters particularly energy recovery does not change from healthy people to people with Down syndrome. However, there are some differences in inter-group through plane walking to obstacle avoidance and it means people with Down syndrome probably use their residual abilities in the most efficient way to achieve the main goal of an efficient energy recovery.

1. Introduction

Motor disability is widespread among individuals with Down Syndrome (DS). From the literature it is well-known that subjects with DS present neuromotor alterations that result in altered movement patterns, of which slowness, longer reaction times, instability, and patterns of muscular co-contractions are some of the most recurrent features (Almeida, Corcos, & Latash, 1994; Aruin & Latash, 1996; Rigoldi, Galli, & Albertini, 2011; Rigoldi, Galli, Mainardi, Crivellini, & Albertini, 2011b; Vimercati, Galli, Rigoldi, Ancillao, & Albertini, 2013). Given these motor difficulties and the self-perceived instability of their movements, subjects with DS tend to trade movement efficiency with movement safety (Vimercati, Galli, Rigoldi, Ancillao, & Albertini, 2011; Vimercati et al., 2013), and as a consequence of both neuromotor deficits and safety strategies

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their movements appear ''clumsy'' respect to the normal population (Latash et al., 1996; Latash, 1992, 2007; Rigoldi et al., 2012).

If most of the studies in literature considered plane walking and standing, a growing interest has been observed in recent literature for studies regarding more complex, functional movements, such as clearing an obstacle while walking. Walking in fact is a motor task that is highly flexible in its adaptation to different situations. Successful interaction with the environment requires the adaptation and combination of fundamental locomotion skills, and this ability to combine movement is essential to daily living (Pearson & Gramlich, 2010). While obstacle crossing is not so challenging in normal gait, obstacles present a significant hazard to persons with neuromotor disabilities, such as DS, who present an increased risk of falls (Virji-Babul & Brown, 2004).

Among the few numbers of studies focused on obstacle avoidance in persons with DS (Virji-Babul & Brown, 2004), studied the mechanism of anticipatory control of gait in relation to the perception of an obstacle. The study was performed in two different conditions: stepping over a subtle obstacle that was placed at a very low distance from the floor (1% of total body height), and an obvious obstacle that was placed at a much higher distance from the floor (15% of total body height). Virji-Babul and Brown (2004) found that subjects with DS are able to extract information about obstacle height and match this information to their movement. However, this information was used without preparing subjects for trials. Vimercati, Galli, Rigoldi, and Albertini (2012) studied the spatiotemporal and kinematic features of obstacle avoidance in teenagers and young adults with DS and in an age-matched control group. They demonstrated that the presence of a destabilizing element, such as the obstacle, enhanced different motor strategies in DS compared to Normal (N), as shown by the parameters of the lower limbs, with a stabilization and safety strategy adopted by DS at the upper limbs. Major differences were found for the pelvis and hip joints patterns in DS compared to controls; while control subjects modified their movement only in the main plane of movement (i.e. sagittal plane) persons with DS displayed a different strategy, with increased values for the sagittal, frontal and horizontal planes. The presence of an obstacle enhanced stabilization and safety strategies at the upper limbs, which were elevated forward and outward in an attempt to stabilize the center of mass and to prevent for possible falls. Despite similar foot elevation, people of control group exploited the elevation to progress forward (longer step lengths) while people with DS did not exploit the elevation to land with their foot further (they produced shorter step lengths). Provided that obstacle avoidance is more expensive, in terms of energy consumption, than plane walking (Chou, Draganich, & Song, 1997), the authors speculated that the ''unexploited'' limb elevation and different clearing strategies in people with DS led presumably to a less efficient clearing than in controls. However, no measurement about either metabolic or mechanical energy consumption is present in the literature in relation to walking with obstacle avoidance in patient with DS.

Human locomotion involves smooth advancement of the body through space in order to minimize mechanical and physiological energy expenditure. While the goal of walking is progression in the forward direction, limb motion is based on the need to maintain a symmetrical, low amplitude displacement of the center of gravity of the head, arms, and trunk in the vertical and lateral directions. This conserves both kinetic and potential energy and is the principle of biological 'conservation of energy' (Waters & Mulroy, 1999) that is an efficient gesture. In normal gait, the energy cost, expressed in $J\,kg^{-1}\,m^{-1}$, depends mainly on gait speed and reaches a minimum at a speed which is defined as optimum, while increases progressively at speeds that are either higher or lower. Generally, subjects with different motor disabilities such as subjects with DS cannot attain a "normal" speed (Rigoldi, Galli, & Albertini, 2011; Rigoldi, Galli, Mainardi, Crivellini, et al., 2011); thus, an increase of cost of gait might well be due partly to the low speed itself. Agiovlasitis, McCubbin, Yun, Mpitsos, and Pavol (2009) suggested a gait pattern with lesser stability and greater energetic cost among adults with DS, particularly at fast speeds. The differences in the center of mass motion and stepping behaviors exhibited by adults with DS was one of the reasons why these individuals showed greater energetic cost during walking with respect to adults without DS. It has been hypothesized that the increase in energy cost could be also related to abnormal kinematics of the lower limbs that disturb the smoothness sinusoidal displacement of the CM (Center of Mass), increasing the mechanical work done to move the CM and disturbing the efficiency of the pendulum-like mechanism (Tesio, Roi, & Moller, 1991).

Given the different movement strategies adopted by subjects with DS when clearing an obstacle and given the lack of studies in the literature regarding evaluation of mechanical energy consumption during obstacle avoidance in people with DS, the aims of this study were (i) the analysis of the differences between the safer condition of plane walking and the less safe condition of stepping over an obstacle within the context of an existing pathology, DS, whose features imply the use of alternative and probably less efficient motor control strategies to reach the goal of maintaining equilibrium during obstacle avoidance and (ii) the comparison of movement efficiency between healthy people and people with DS in terms of energy cost.

2. Materials and methods

2.1. Participants

The study was approved by the ethical committee of IRCCS San Raffaele Pisana, Tosinvest Sanità, Rome, where the walking trials for data capturing took place. The subjects and their legal tutors gave their informed consent to the study. A total of 39 individuals were included in our study, 21 subjects with DS (the mean age: 21.6 ± 7 years and the age range: 18–29 years) and one control group (*N*) of 18 subjects (the mean age: 25.1 ± 2.4 years and the age range: 21–30 years) with no motor or cognitive deficit. Mean age, height, and weight were obtained for each group (Table 1). Inclusion criteria for the people in DS group were adult age, no severe obesity (normal to overweight Body Mass Index, $18.5 < BMI < 30$), low to medium intelligence quotient