Human Movement Science 58 (2018) 260–267

Contents lists available at ScienceDirect

Human Movement Science

journal homepage: www.elsevier.com/locate/humov

Full Length Article

Gait strategies to reduce the dynamic joint load in the lower limbs during a loading response in young healthy adults

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ARTICLE INFO

Keywords:
Ground reaction force
External joint moment
Loading rate
Gait
Dynamic joint load

ABSTRACT

Reducing external joint moments during gait can lead to a reduction in dynamic joint load. There has yet to be a detailed investigation of gait strategies that can reduce external joint moments by decreasing the magnitude of ground reaction force (GRF) without reducing the walking speed. The objectives of this study were to verify whether it is possible to reduce external joint moments by decreasing the GRF magnitude without reducing the walking speed and to identify the alternative walking strategy involved in young healthy adults. This study included 14 young healthy subjects. They performed two types of walking: normal and impact reduction walking. For impact reduction walking, the subjects walked in a manner that reduced the impact upon foot contact. Cadence and step length were unified between the two conditions. The walking speed, peak value of vertical GRF, braking-accelerating force, loading rate, joint angle, and external joint moments of the two conditions were recorded and compared. No significant difference was noted in the walking speed. However, the first peak of vertical GRF, braking force, and loading rate during loading response were significantly reduced during impact reduction walking, and external joint moments in the hip, knee, and ankle joints were reduced. In contrast, the second peak of vertical GRF, hip extension angle, and external ankle dorsiflexion moment were significantly increased during terminal stance. Our data imply that the ankle joint function during the terminal stance is important in reducing the dynamic joint load in the contralateral leg during the loading response.

1. Introduction

During walking, the body constantly receives ground reaction force (GRF). This force causes an external moment at the joints in the lower limb. The external joint moment during gait is considered an indicator of dynamic joint load in the lower limbs. The external joint moment is also associated with degenerative joint changes. Particularly, the external knee adduction moment (KAM) is highly correlated with the medial compartment contact force of the knee (Zhao et al., 2007) and has been shown to be a strong predictor for the development (Baliunas et al., 2002; Gök, Ergin, & Yavuzer, 2002), disease progression (Miyazaki et al., 2002), and severity (Anne Mündermann, Dyrby, Hurwitz, Sharma, & Andriacchi, 2004; Sharma et al., 1998) of medial compartment knee osteoarthritis (OA). Recently, the external knee flexion moment (KFM) has also been reported to be associated with the progression of medial compartment knee OA (Chehab, Favre, Erhart-Hledik, & Andriacchi, 2014). Thus, reducing the external joint moment is important to relieve the dynamic joint load, which could contribute to the prevention of OA in the lower limbs.

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https://doi.org/10.1016/j.humov.2018.03.002
Received 2 July 2017; Received in revised form 27 February 2018; Accepted 1 March 2018
Available online 12 March 2018
0167-9457/

Under static conditions, the external joint moment is simply expressed as the product of the GRF magnitude and the moment arm. Either or both of these factors must be decreased to reduce the external joint moment. This principle can be applied in part to dynamic moments during walking, where inertial components of segment movement should also be considered. Many studies have reported strategies to reduce KAM including walking with reduced speed (Anne Mündermann et al., 2004; Robbins & Maly, 2009), increased step width (Fregly et al., 2008), pointing the toes outward (second peak only) (Guo, Axe, & Manal, 2007; Hurwitz, Ryals, Case, Block, & Andriacchi, 2002) or inward (first peak only) (Favre, Erhart-Hledik, Chehab, & Andriacchi, 2016), and increased lateral trunk lean (Hunt et al., 2008; Mündermann, Asay, Mündermann, & Andriacchi, 2008). Besides using these modifications, KAM can also be reduced with the use of a cane in the contralateral hand to the study knee (Kemp, Crossley, Wrigley, Metcalf, & Hinman, 2008), valgus knee braces (Draganich et al., 2006), and lateral wedge insoles (Butler, Marchesi, Royer, & Davis, 2007; Kakihana et al., 2005). However, most of these gait modifications and assistive devices are used to shorten the moment arm. Apart from the use of canes, reducing the walking speed is the only strategy to reduce KAM by decreasing the GRF magnitude. In fact, the magnitude of the GRF is proportional to the walking speed or the step length (Chiu & Wang, 2007; Chung & Wang, 2010). Moreover, a change in the GRF magnitude is considered to influence every external moment occurring in the lower limb joints, not just in the knee joint. Given that 37.6% of patients with radiographic knee OA also have radiographic hip OA (Elliott et al., 2005), reducing the GRF magnitude to relieve the dynamic joint load in all joints in the lower limbs is an important strategy to consider. However, reducing walking speed is an undesirable walking modification because it limits outdoor activities, such as crossing the street, changing trains, or reaching a specific destination within a given time. Hence, the development of walking strategies to change the GRF magnitude and reduce external joint moments without decreasing the walking speed is necessary. Investigations of such walking strategies have not been previously reported. Therefore, the objectives of this study were to verify whether the external joint moments could be reduced by decreasing the GRF magnitude without reducing the walking speed and to identify the alternative walking strategy involved in young healthy adults. Before conducting experiments with patients, we first investigated potential gait modifications and effective instructions to reduce the dynamic joint load as much as possible. Thus, this study included only young healthy subjects who could alter their gait flexibly.

2. Materials and methods

2.1. Subjects

This study involved 14 young healthy subjects (six men and eight women: mean age, 21.6 ± 0.7 years, mean height, 163.1 ± 10.1 cm, and mean mass, 58.6 ± 9.1 kg). Subjects were excluded if they had any lower limb injuries or history of orthopedic surgery. All subjects provided informed written consent, and the study was approved by our institutional review board.

2.2. Testing protocol

A 6-m walkway, with two force plates embedded in the center, was used for all walking trials. The starting position for each subject was determined such that the right foot could land on the first force plate, and at the subsequent step, the left foot could land on the second force plate. The cadence was adjusted to 110 steps/min using a metronome and was set with reference to the average cadence rate in adults (Perry & Burnfield, 2010), although differences were found in the preferred step length among subjects. All subjects performed two types of walking trials: normal and impact reduction walking. In the normal walking trials, each subject walked with their preferred step length. After consistent step length and foot contact points were observed, we marked the bilateral foot contact points with tapes on the force plate and measured the left step length as the distance between these tapes. Based on this length, marking tapes were placed on the walkway as guides for foot contact points for both legs. Three separate trials were then recorded. Subsequently, the subjects were instructed to walk in a manner that minimized the impact to both legs when their feet touched the floor, while maintaining their step length and normal walking cadence. Marking tapes were used to confirm that the step length did not deviate from that of normal walking, and the subjects were required to walk without looking at the tapes. An investigator confirmed whether or their feet made floor contact on the marking tapes and provided feedback to the subjects. The first peak (Fz1) of the vertical ground reaction force (VGRF) of the left leg (obtained from the second force plate) was determined as the analysis target. The VGRF waveform of the left leg was projected onto a screen placed in front of the subjects to provide feedback. In the normal walking trials, 90% of the average Fz1 was calculated. Before practicing impact reduction walking, an investigator pointed to a line on the screen corresponding to 90% of Fz1 in the normal walking process and gave the following verbal instruction: "Please reduce impact to this line when each foot touches the floor." The reduction of KAM observed in the previous studies investigating gait modification was approximately 10–20% (Favre et al., 2016; Fregly et al., 2008; Robbins & Maly, 2009). Thus, the target VGRF was set to 90% of normal walking in this study, anticipating a realization of the same results as in the previously cited studies. The subjects practiced impact reduction walking while gaining visual feedback from the left leg until Fz1 was reduced to approximately 90% of normal walking. After some practice, ten trials were recorded, and the three trials exhibiting the greatest reduction of Fz1 were selected for analysis. We did not record trials wherein either step length or cadence clearly decreased.

2.3. Gait analysis

Kinetic and kinematic data were recorded using a three-dimensional motion analysis system, the VICON Clinical Manager (VCM) software (Vicon Nexus; Vicon Motion System Ltd., Oxford, UK) and force plates (Kistler Japan Co., Ltd.; Tokyo, Japan). Sampling