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Lower extremity muscle activity during descent from varying step heights

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ABSTRACT

During step descent, lower extremity musculature is critical for positioning the foot and ankle for initial contact and stabilizing the structures following contact. Although continuous stair descent has been extensively examined, curb/single transition steps where many injuries occur requires further study. The purpose of this study was to identify the influence of landing strategy and step height on lower extremity muscle activity of uninjured individuals during transition step descent. Twenty-two participants walked along a level walkway, stepped down a single step (heights: 5-cm, 15-cm, 25-cm) landed with the heel or forefoot, and continued walking. Muscle activity of the leading leg's peroneals, tibialis anterior, and medial gastrocnemius were recorded 200 ms before and after initial contact. Two-way Repeated Measures ANOVAs within the three step heights and two landing strategies were run for both the pre- and post-contact periods. Step height by landing strategy interactions existed during the pre-contact periods for all three muscles. During the post-contact period, all muscle activity increased with each step height increment. Additionally, the medial gastrocnemius and tibialis anterior demonstrated significant landing strategy differences. This study highlights the importance of considering both landing strategy and step height when designing or interpreting investigations of transition step negotiation.

1. Introduction

Over 25% of the ankle sprains requiring hospital care over a four-year period were the result of a fall from stairs (Waterman et al., 2010). Further, falls on stairs occur three times more often during descent than ascent (Templer, 1992). During step descent, lower extremity musculature is critical to the positioning of the foot and ankle for initial contact and stabilizing the structures following contact. The extrinsic muscles primarily involved in providing posterior, anterior, and lateral ankle support are the soleus and gastrocnemius, the tibialis anterior, and the peroneals, respectively. However, results of previous studies examining muscle activity of the tibialis anterior and gastrocnemius or triceps surae during step descent have been inconsistent. Factors contributing to the inconsistencies may have included the type of descent (continuous, transition steps), the activity before/after descent (walking, standing), the step height, and the landing strategy (Eteraf Oskouei et al., 2014; Freedman and Kent, 1987; Joseph and Watson, 1967; Mann and Inman, 1964; McFadyen and Winter, 1988). Additionally, although the peroneal muscles function to provide lateral stability to the ankle joint and support the medial longitudinal arch, the activity of the peroneals during step negotiation has been limited to a single study that reported increased medio-lateral instability of the ankle caused greater peroneal activation (Yang et al., 2016).

Furthermore, despite over 30% of stair incidents occurring on the transition step to or from level walking and a single stair or curb being listed as one of the top factors that may cause step falls (Duckham et al., 2013; Templer, 1992), the majority of step literature has focused on muscle activity during continuous or mid-staircase descent. This is significant given the results of a study by Andriacchi et al. (1980) that examined differences in muscle activity during continuous descent versus the transition step to level walking. For both the tibialis anterior and the gastrocnemius, muscle activity differed based on the step examined. Thus, results of continuous step descent studies cannot be generalized to transition step descent.

In addition to the type of step descent, the motion before and after encountering the step can also influence muscle activity. With respect to the approach, Peng et al. (2016) identified muscular activity differences in the two approach strides before step descent. These adjustments during the approach strides suggest the activity prior to the descent may also influence the activity during step negotiation. Previous single step or transition step studies have often had participants stand statically before beginning step descent (Freedman and Kent, 1987; Yang et al., 2016). Therefore, the results from these studies may not be generalizable to the activity associated with transition step negotiation that is preceded by level walking.

Another factor that may influence muscle activity during transition step negotiation is step height. Freedman and Kent (1987) examined the effect of varying single step heights (0-, 2.5-, 5-, 10-, 20-cm) on tibialis

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anterior and gastrocnemius activity. Unfortunately, the study was not able to conduct the statistical analysis of muscle activity across individual step heights due to the presence of mixed landing strategies (heel, forefoot) within and between participants on several heights. The issue of different landing strategies may be unique to transition step negotiation. Unlike continuous step descent in which the tread depth may constrain landing strategy to the forefoot, there is no such constraint during the transition step to level walking. Further, although Freedman and Kent (1987) as well as van Dieen and Pijnappels (2009) have found that landing strategy changes from the heel to the forefoot with increasing step height, the height the transition occurs varies across individuals. To date, no study investigating the influence of transition step height on ankle/foot muscle activity has also considered the potential influence of the landing strategy. The previous studies investigating step height have either required participants to utilize a pre-determined landing strategy (Hortobagyi and DeVita, 1999), or combined the results of both strategies at a given height (Lythgo et al., 2007). Identifying the influence of landing strategy and step height on ankle/foot muscle function during transition step negotiation may ultimately contribute to development of improved prevention and rehabilitation programs aimed at decreasing injury risk during transition step negotiation.

Therefore, the purpose of this study was to identify the influence of landing strategy and step height on lower extremity muscle activity of uninjured individuals during transition step descent. Given their role in both providing stability to the ankle and the distal foot, the function of the peroneals was of primary interest. Due to the need to position the foot in plantarflexion for the forefoot landing strategy and the fact that a more plantarflexed foot position is associated with a less stable ankle joint, the peroneals and medial gastrocnemius were anticipated to be more active before initial ground contact (pre-contact) and during early weight acceptance (post-contact) during the forefoot landing strategy compared to the heel strategy. Additionally, the forefoot strategy was hypothesized to be associated with increased peroneal and medial gastrocnemius activity both pre- and post-contact with higher step heights to prepare and provide support for a less stable ankle joint position and increased distal foot load. The peroneal and gastrocnemius activity during the heel landing strategy was expected to remain at similar levels across step heights due to the dorsiflexed landing position. With respect to the tibialis anterior, activity was hypothesized to be greater during the heel versus forefoot landing strategy due to the need to maintain a dorsiflexed versus plantarflexed position for initial contact and control lowering of the forefoot versus heel during early weight acceptance. Further, tibialis activity for the forefoot strategy was projected to decrease with increasing step height as ankle stability may become more dependent on the peroneals and gastrocnemius. For the heel strategy, it was expected the tibialis anterior activity would increase at greater step heights to oppose the larger forces, and thus plantarflexor moments, at initial contact.

2. Methods

2.1. Participants

Twenty-two healthy participants (12 female, 10 male; age: 25.7 ± 5.6 years; mass: 76 ± 18.6 kg) were recruited for the study from the University and surrounding community. A previous study of step descent across differing step heights primarily focused on kinematics and muscle fascicle length of the gastrocnemius, found a large effect size of gastrocnemius activity between step heights (Spanjaard et al., 2008). Based on this study, to reach a power of 0.8 with alpha = 0.05 and a large effect size 5 subjects would be needed. Assuming not all muscles would have a large effect size a power analysis with a moderate effect size (Effect size = 0.3) was calculated requiring a minimum of 20 subjects. To participate, subjects must have been between the ages of 18–40 years, not wear bifocals, have weight bearing dorsiflexion range of motion of greater than 25°, have had no history of surgery to the lower extremity and no lower extremity injury within the past six months. Ankle health was assessed via the Cumberland Ankle Instability Tool (CAIT) (Hiller et al., 2011, 2006). To qualify, individuals had to score 28 or greater on the CAIT (average score: 29.5 ± 0.67). A score of 28–30 on the CAIT indicates the individual is unlikely to have perceived instability, while a score of 27 or below indicates the presence of perceived instability. Prior to participation, all subjects were informed of the study procedures and asked to sign an informed consent form approved by the University's Institutional Review Board.

2.2. Study protocol

Participants walked at a self-selected pace wearing a standardized sandal (Maui and Sons, Pacific Palisades, CA) along a 5 m raised runway, stepped down a single step and continued walking another 3 m. The sandal was used as most daily activities are conducted in a shod condition and the use of footwear is consistent with previous studies (Freedman and Kent, 1987; Joseph and Watson, 1967; Vallabhajosula et al., 2012; van der Linden et al., 2007). Additionally, the standardized sandal was used rather than personal shoes to allow placement of markers for a multi-segment foot model (not presented here) and to eliminate potential differences due to varying degrees of shoe support. At each step height, three practice trials were given to familiarize participants with the step height, the sandals, and establish the participants' self-selected speed. Speeds were monitored in real time via electronic timing gates. During the subsequent step trials, the participant's approach speed was maintained within 10% of their practice trial speed to ensure consistency across the trials. Participants completed trials at 5-cm, 15-cm, and 25-cm step heights. Custom built 5-cm platforms were either placed under, or removed from underneath, the runway to increase or decrease the step height, respectively. The increasing or decreasing step height progression was counterbalanced by participant to control for any learning or fatigue effects. Trials were repeated with no instruction on landing until ten trials with the same landing strategy (heel or forefoot) at each step height were performed (individual's preferred strategy). To enable comparison of the heel and forefoot strategy at each height, participants were then asked to complete additional trials with the opposite strategy (individual's requested strategy). The additional trials were repeated until each individual completed ten successful trials with the requested strategy. Preferred landing strategy trials were collected on all step heights prior to collecting the requested strategy. Step landing strategy was assessed visually during the performance of each trial, with additional examination of a reference video if needed. Heel strike was defined as initial contact in a dorsiflexed position and forefoot strike was defined as initial contact with the foot in a neutral to plantarflexed position.

A Noraxon Telemyo Electromyographical (EMG) system (Scottsdale, AZ, USA) and Noraxon Ag/AgCl surface electrodes (Scottsdale, AZ, USA) were used to assess muscle activity of the peroneals, tibialis anterior and medial gastrocnemius during the step descent trials. Skin preparation consisted of shaving and cleansing the skin with alcohol and electrode placement followed standardized techniques of Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles (SENIAM) (Hermens et al., 1999) and the modifications proposed by Sacco et al. (2009). Prior to data collection, appropriate manual muscle testing was performed for each muscle to confirm correct EMG placement. During the trials, muscle activity was monitored beginning 200 ms pre-contact through 200 ms post-contact (Delahunt et al., 2006; Gutierrez et al., 2012). Initial contact (10 N threshold) and peak vertical landing force during the 200 ms after initial contact were determined via a force plate (AMTI, Inc., Watertown, MA) sampling at 1000 Hz.