Effects of lower extremity power training on gait biomechanics in old adults

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1. GENERAL INTRODUCTION

Level walking gait is the most common form of human locomotion and is an integral component of many daily tasks. Habitual gait velocity, i.e., the speed at which a person chooses to walk given no specific instructions or environmental limitations, is an accurate measure of health and function and is easy to administer. Indeed, slow gait is a predictor of adverse clinical events, such as falls, declines in mental health, cognitive functioning, and even all-cause mortality [1–8]. Additionally, slow walkers have greater risks for mobility disabilities, dependency, institutionalization, and hospitalization, which all cause a decline in quality of life [1,5,9,10]. Habitual gait velocity is relatively stable throughout adult life until the seventh decade; thereafter, gait velocity decreases by 7-20% per decade [11]. Specifically, a healthy 25-year old generally walks at 1.38m/s compared to 1.29m/s at age 65 and 0.96m/s at age 85 [11]. In view of the increasing portion of elderly people in the population due to an increase in life expectancy, maintaining adequate levels of gait velocity and delaying the onset of mobility impairments have become universal health care priorities.

It is well established that exercise training is an effective tool for increasing walking speed in old adults [12]. However, the biomechanical mechanisms responsible for improvements in old adults’ gait velocity after exercise training are not understood. More insights into the involved mechanisms can increase the effectiveness of exercise interventions that aim to attenuate the age-related reductions in mobility function.

1.1. HISTORICAL BACKGROUND

The present-day knowledge of the effects of age on the mechanics of human locomotion is due to the contributions by many scientists. Until the mid-nineteenth century, a lack of technology limited the objective recording of human gait and locomotor studies were based on primarily anatomical knowledge and empirical evidence [13–15]. In the mid-nineteenth century, the Weber brothers [16,17] studied human gait using a telescope with a calibrated graticule and provided the first objective experiments. By the end of the nineteenth century, Muybridge [18] developed photographic methods to record instantaneous pictures of locomotion displacements. Marey and his group [19–22] improved these methods and developed the first version of the modern force plate using a pneumatic mechanism. Shortly after, Braune and Fischer [23–27] employed fundamental mechanical principles and performed a variety of kinematic and kinetic studies on military personnel carrying backpacks and their methods of study are still recognized as valid today. In the mid-twentieth century, Inman and Eberhart [28,29] used kinesiological electromyography (EMG) to relate muscle function to joint motion and phases of gait in disabled populations. From that point on, gait analysis became a useful clinical tool through the efforts of Perry [30–32] and others [33–36]. Around 1980, David Winter’s pioneering work [37–40] profoundly influenced the course of clinical gait analysis as he popularized the routine use of inverse dynamics to compute
moment and powers. These historical efforts resulted in hundreds of motion analysis laboratories operating around the world today and gait analysis has been increasingly used for both clinical and research purposes.

1.2. THE ELDERLY GAIT
The gait pattern of an elderly person is different from that of a young adult. It is characterized by a stooped posture, increased knee and hip flexion, reduced ankle joint ranges of motion, diminished arm swing, increased time with both feet on the ground, and wide and short steps [41–47]. The kinetic changes associated with these age-related changes in kinematic pattern include reduced torques and powers at all three lower extremity joints, and especially so at the ankle [43,45,46,47]. Because kinematic and kinetic patterns are a function of stride length and velocity [43,48], later studies compared gait biomechanics of young and old adults walking at identical speeds. These studies revealed that shorter steps, higher cadence, larger hip joint range of motion, and reduced ankle joint range of motion in the elderly were still present when walking speeds were matched [49–52]. The kinetic pattern also differed at matched speeds and old compared with young adults generate less work around the ankle joint and generate more work around the hip joint, with little to no change in work around the knee joint [49–52]. Aging thus affects the biomechanics of gait, leading to a redistribution of lower extremity mechanical output and altered control of the lower extremity muscles during walking. The distal-to-proximal shift in muscle function or, “biomechanical plasticity”, is robust and is present even in fit and trained old adults [53–55].

Aging also alters the neural activation patterns of the lower extremity muscles during gait. Old compared with young adults generally walk with increased coactivity around the knee and ankle joints [56–59]. Coactivity is the concurrent activity of agonist and antagonist muscles surrounding a joint and increased coactivity is associated with increased joint stiffness and thereby enhanced joint stability [60,61]. Old adults probably use the coactivity-mediated increase in lower-extremity stiffness in order to prepare the limb for impact and compensate for age-related reduction in muscle strength and power [60]. The age-related increase in coactivity is one of the factors that is associated with a ~20% higher metabolic cost of walking in the old compared with young adults [56,61].

1.3. POWER TRAINING TO IMPROVE GAIT IN THE ELDERLY
Preventing mobility disability is necessary for maintaining independent function in old age [1]. Impaired mobility is strongly associated with low levels of lower extremity extensor strength and power [55,62]. Muscle strength is the ability to produce voluntary muscle force and muscle power is the product of muscle force and the velocity of shortening and it is the rate of muscle work done to the skeletal system [63]. Although muscle strength and power are two inter-related mechanical properties of muscle, muscle power declines earlier and more rapidly with age [64–67], and is a stronger predictor of
functional performance, including gait velocity [62,68–73]. Lower extremity extensor power is a key determinant of locomotor performance and logically recognized as an efficient target for interventions that aim to improve gait velocity. Progressive resistance training is an effective way to maximize muscle force and to improve muscle power in the elderly. While traditional strength training is typically performed with heavy weights (i.e., at 80% of maximal muscle force) and slow movement speeds, muscle power can best be improved by training protocols that incorporate exercises with moderately heavy weights (i.e., at 60% of maximal muscle force) moved at high movement velocity during the concentric phase [73–76]. In addition to improvements in muscle performance, power training also leads to increases in neuromuscular activation of the trained muscles [77] and improve gait velocity [78]. Despite these beneficial results, it is unclear how the improved physiological capacities (i.e., improved muscle strength and power, as well as increased neuromuscular activation) evoke kinematic, kinetic, or neuromuscular changes during gait that ultimately lead to faster walking in old adults. Overall, the biomechanical mechanisms of power training-induced adaptations in old adults’ gait velocity have not yet been identified or even studied comprehensively.

1.4. OUTLINE OF THIS THESIS

The main objective of the present thesis is to increase our understanding about the biomechanical mechanisms of how lower extremity power training increases walking speed in old age. Chapter 2 provides a review of the existing literature on the effects of interventions on gait biomechanical in general and, in particular, how strength and power training improve walking speed in old age. Based on the limited available evidence, chapter 2 discusses candidate mechanisms of how strength and power interventions can evoke adaptations in gait biomechanics that potentially underlie improvements in old adults’ gait velocity. By using the knowledge gained from chapter 2, chapter 3 provides a detailed description of the design and methodology of the Potsdam Gait Study (POGS), which aims to determine the biomechanical mechanisms of how lower-extremity power training evokes adaptations in walking speed in old age. Next, chapters 4–6 describe the effects of the in chapter 3 described power training study on a series of biomechanical and neuromuscular outcome measures. Specifically, chapter 4 is an evaluation of training-induced changes in lower-extremity power on stride characteristics and joint kinematics during gait. Chapter 5 focusses on the effects of power training on joint kinetics during gait. Moreover, chapter 6 shows the effects of power training on lower extremity muscle activity and coactivity during gait. Last, chapter 7 provides a general discussion of the finding reported in this thesis.

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