THE METHOD OF USING PHASE PLANE PORTRAITS AND FIRST RETURN MAPS TO EXAMINE TURNING

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INTRODUCTION

The risk of falling and injury maybe exacerbated during complex tasks such as avoiding obstacles and turning corners, which occur during daily community and household ambulation. Previous research has shown falls that occur during a turn are more likely to result in serious injury [1]. Recent publications of able-bodied subjects have highlighted the kinematic and kinetic differences associated with turning [2,3]. This study examined the effect of turning on dynamic equilibrium using phase plane portraits and first return maps [4].

METHODS

One able-bodied subject gave informed consent to participate in this IRB approved protocol. Average self-selected walking speed (SSWS) over five straight walking trials was determined using a timing light system. Steady-state straight-line walking data was collected over 100 continuous steps on a treadmill at SSWS. Full body gait kinematics were collected using a 10-camera Vicon 612 system and Plug in Gait (Lake Forest, CA.). Next, the subject walked along a 1m-radius circular path at the previously measured straight-line SSWS speed and data was collected over 100 steps. A constant speed 1m-radius path was selected to elucidate the mechanisms of turning while under steady-state conditions [2]. Angular velocity was calculated by numerically differentiating the angular position data. Hip, knee and ankle sagittal plane angle were then plotted versus angular velocity. Toe off was identified at the moment of peak ankle joint center vertical velocity. The toe off event was then used to create first return maps of sagittal plane angle (θ_i) at toe off versus the angle at the next consecutive toe off (θ_{i+1}).

RESULTS AND DISCUSSION

The phase plane portraits for straight-line walking were reasonably consistent with previously reported data [4]. Average center of mass velocity was determined post data collection to be 1.6 m/s, which is within 10% of the straight-line SSWS (1.5 m/s). Therefore, differences between turning and straight kinematics were not likely related to changes in walking speed [2]. Turning demonstrated increased stride to stride variability (figure 1). Toe off during turning occurred at higher angular velocities compared to straight-line walking (figures 1A & 1B). Stride to subsequent stride ankle angle differences were larger for turning than straight (3.5 $\pm$ 2.7 vs. 2.0 $\pm$ 1.6 degrees, respectively). The first return maps portray the wider distribution of stride to stride ankle angle of turning compared to straight (figures 1C & 1D). The circles in these figures, whose radii are two standard deviations from the mean and centered on the diagonal line, signify dynamic steady-state. The standard deviation from the mean for turning was larger than straight (3.9 vs. 2.8 deg, respectively).

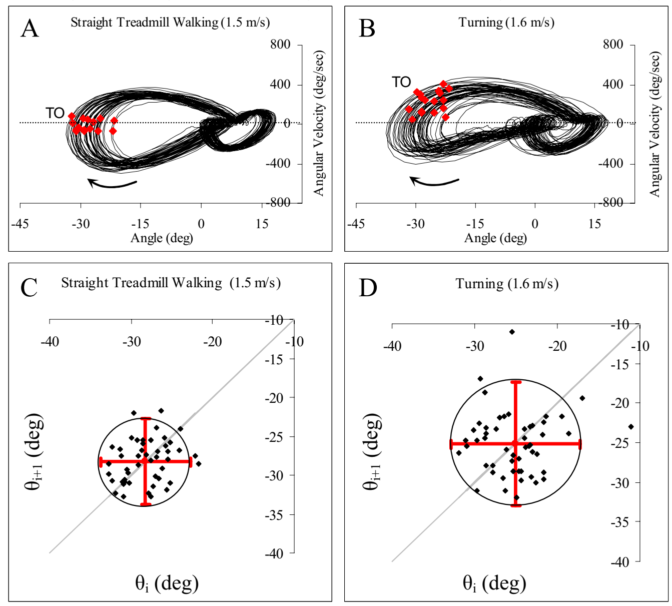

Figure 1: Ankle phase plane portraits of straight treadmill walking (A) and walking along a 1m-radius circular path (B). The red data points signify toe off (TO) over multiple strides. The arrow indicates direction of progression. Example first return maps for the ankle at toe off comparing treadmill straight-line walking (C) to turning (D). The radii of the circles signify two standard deviations from the mean.

More subjects must be examined to determine whether these differences are statistically significant. The preliminary data suggests that these graphical tools demonstrate the ability to identify increased variability associated with more complex tasks, which may relate to falls and injury. Pathologic individuals have an increased risk of falling, which may be associated with an increase in stride to stride variability. Therefore, these tools may be capable of determining the efficacy of rehabilitation treatments, surgical procedures and prosthetic componentry.

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