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A Pilot Study

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Self-induced Gyroscopic Torques in Lower Extremities During Gait: A Pilot Study

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Abstract To affect functional relevant task-space gait parameters such as foot placement or progression angle, conventional lower-limb robotic gait rehabilitation devices require active control and synchronization of their actuators. As an alternative, we propose the use of gyroscopic actuators, portable actuators that have the ability to generate torques that are caused by and therefore intrinsically synchronized with the swing motion of the legs. Here we investigate the kinematic and kinetic effects at hip-joint level of self-induced gyroscopic torques of a shank-worn gyroscopic actuator. Preliminary results show the wearer's swing leg motion can induce gyroscopic effects that significantly alter the kinematics of the hip-joint ($p < 0.05$) for both tested conditions in hip-joint endo/exo rotation and ab/ad-duction.

1 Introduction

Wearable gait rehabilitation devices face large challenges in hardware and control. Conventional lower-limb wearable gait rehabilitation devices require actuators and transmission structures that span multiple joints to affect functionally relevant task-space gait parameters such as foot placement or progression angle. Here gyroscopic actuators can affect such parameters in a more direct fashion, via free couple moments applied at the shank. We have already demonstrated the higher effectiveness of such an approach for step length [2]. Moreover, to affect these parameters, conventional wearable gait rehabilitation devices require complex methods to generate references for the control of assistive torques which must be synchronized to a user's individual gait, for example using gait event detection methods and physiological reference

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patterns. Also in this context, passive gyroscopic actuators can offer a solution: a drastically different principle that does not require any explicit control, namely self-induced gyroscopic torques (SIGTs). By mounting fast spinning wheels on a user's legs, the swing of the leg acts as the control input of the gyroscope and thereby inducing gait-synchronized gyroscopic torques that can affect other degrees of freedom (Figs. 1b, c). Here, we investigate how the swing motion of the leg can directly affect hip-joint kinematics and kinetics in endo/exo rotations (EXR) and ab/ad-duction (ABD) and thus step width and progression angle [1].

We hypothesized that these torques would result in significant changes in gait kinematics, most specifically in hip-joint EXR and ABD, and kinetics, showing significant changes in muscle activity. We assessed these hypothesis using a set of passive toy gyroscopes attached to the shank of the non-dominant leg of healthy subjects, instrumented motion capture and surface EMG sensors.

2 Materials and Methods

To evaluate the effect of SIGTs in hip kinematics during gait, we attached six motorized toy gyroscopes in two predefined directions (Self-induced ABD Fig. 1b and EXR Fig. 1c) to the shank of the non-dominant leg (perturbed leg) via a rigid shin-guard (Fig. 2c). Dead weight was also attached to the dominant leg (sound leg) to compensate for the effect of the added mass in the perturbed leg. The 6 gyroscope's spinning wheels were aligned in parallel to increase the overall gyroscopic effect.

The protocol consisted of a simple walking task. Participants walked back and forth at a comfortable walking speed on a 4 m-long straight path with and without the

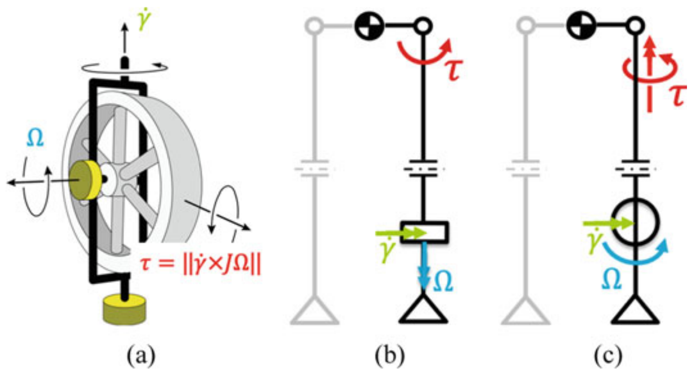
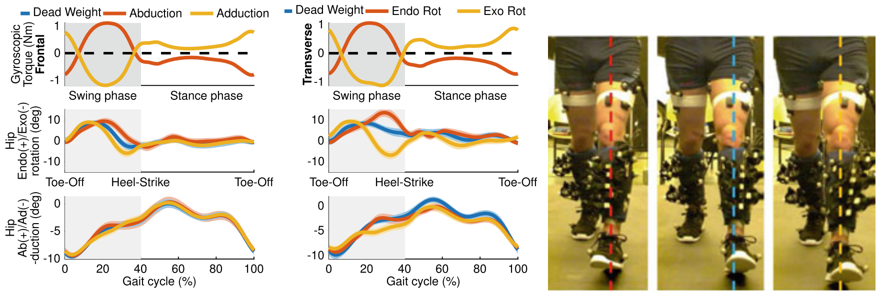


Fig. 1 **a** Schematic of a gyroscopic actuator. Once the wheel spinning at a fast angular speed $\boldsymbol{\Omega}$ is 'gimbaled' by an angular velocity $\dot{\boldsymbol{\gamma}}$, a gyroscopic torque $\boldsymbol{\tau}$ is generated about a mutually perpendicular axis. **b**, **c** show the placement and orientation of the gyroscope in the shank to self-induce ab/ad-duction and endo/exo rotation respectively. The self-induced gyroscopic torque is generated by the regular swing of the leg ($\dot{\boldsymbol{\gamma}}$) acting as a gimbal



(a) (b) (c)

Fig. 2 Left hip-joint kinematics (bottom) and gyroscopic torques (top) of self-induced **a** ab/adduction (Frontal plane) and **b** endo/exo rotation (Transversal plane) for representative participant S3. Solid lines represent the mean and shaded areas the standard deviation of the recorded 78 gait cycles for S3. **c** Visual comparison of self-induced endo/exo rotation at heel strike. Conditions dead-weight (middle) and self-induced exo- (right) and endo- (left) rotations at heel strike of a representative stride

device. While donned, we tested the device in 5 configurations based on the direction of the SIGTs on the leg; 1- Dead-weight ‘DW‘ (No torque), 2a,2b- Frontal plane torque resulting adduction and abduction respectively (Fig. 1b), 3a,3b- Transverse plane torque resulting in endo/exo rotations respectively (Fig. 1c). In conditions 2a and 3a the spinning direction of the flywheel was reversed with respect to that of 2b and 3b respectively.

Three healthy subjects, one female and two males (Id: S1, S2, S3, age: (29.7 $\pm$ 2.5 years); height: (1.7 $\pm$ 0.07 m); mass: (65.6 $\pm$ 8.7 kg) were recruited with approval from the Human Research Ethics Committee of TU Delft. We conducted the experiment in accordance with the recommendations of the review board. All subjects were volunteers and gave their written informed consent prior to participation and for use of their data.

We measured gait kinematics using a marker-based motion capture (Qualisys). In addition, we used 6 EMG wireless sensors (Delsys) to record muscle activity of the perturbed leg *tensor faciae latae*, *adductor longus*, *gluteus medius*, *semitendinosus*, *biceps femoris* and *rectus femoris*.

Motion capture data was processed using QTM (Qualisys) and ‘Visual 3D (C-Motion)’. Gait analysis, EMG filtering and statistical analysis of the data was performed in MATLAB 2018b (MathWorks).

One-dimensional statistical parametric mapping was used to check for significant differences of time-series hip joint EXR and ABD angles and filtered EMG using the swing phase as ‘Region Of Interest’.

3 Results and Discussion

Preliminary results showed that the SIGTs significantly affected hip-joint kinematics during swing phase. Transverse plane SIGTs affected significantly hip EXR ($p < 0.001$, Fig. 1c middle) opposed to the weaker effect, yet significant, of frontal plane SIGTs in hip ABD ($p < 0.05$, Fig. 1b bottom). This can be explained by the difference in magnitude of the rotational inertia between both EXR and ABD conditions. Interestingly both transverse and frontal plane SIGTs also significantly affected ($p < 0.001$) hip ABD and EXR (Fig. 1b middle and Fig. 1c bottom). This could be explained by the musculoskeletal motion coupling between ABD and EXR.

Opposed to what we hypothesized, muscle activity of any of the 6 instrumented muscles did not show any significant differences during swing phase of both EXR and ABD conditions of the SIGTs respect to the baseline DW. Three main reasons could explain the lack of significant differences in muscle activation. (i) Limited access to endo/exo dominant rotators due to limitation of surface EMG. (ii) Weak SIGTs effect in ABD due to high inertia of the leg and low angular momentum of the gyros, and (iii) Lack of strong corrective strategies against the SIGTs, presumably due to the lack of challenge in balance caused by the weak SIGTs of the device despite the strong kinematic effects in some conditions.

4 Conclusion

We showed that self-induced gyroscopic torques in lower extremities are suitable to significantly alter hip endo/exo rotation or ab/ad-duction. This passive effect can be beneficial in therapy training to reinforce balance compensatory strategies or suppress undesired non-compensatory ones. In this sense passive gyroscopic actuators might be alternative to conventional wearable gait rehabilitation devices given that their intrinsically gait-synchronized torques do not require the implementation of any controller.

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