The Effects of Assist Algorithms for Gait Assist Robot on Physical Stability During Unplanned Gait Termination

1st Yoshikazu Sakashita
Department of Textile Science and Technology
Shinshu University
Ueda-city, Japan
23fs308a@shinshu-u.ac.jp

2nd Yasuhiro Akiyama
Department of Textile Science and Technology
Shinshu University
Ueda-city, Japan
akiyama_yasuhiro@shinshu-u.ac.jp

***Abstract*—One of the challenges in the daily use of the gait assist robot is stability, which sometimes decreases after gait perturbations. Therefore, it is necessary to analyze and quantify the effect of the assist on the wearer's stability after gait perturbations such as sudden gait termination. This study focuses on unplanned gait termination and investigates the effect of assistive torque on the wearer's gait parameters. The experiment was performed to compare the parameters of the wearer under the conditions that the gait assist was continued and stopped after the gait terminate stimulus. Results of the experiment suggested that gait assistance whose torque was less than half of the torque required for normal gait did not significantly change the wearer's movement during unplanned gait termination.**

***Index Terms*—Wearable robots, Gait analysis, Gait termination**

I. Introduction

With the increase in aging populations, the demand for exoskeletons is rising. In particular, exoskeletons that can be used in daily life are required. For this purpose, safety is a crucial factor. However, safety metrics for wearable assistive robots could not cover the situation in the daily living environment [1]. The gait perturbations, such as steps, turns, and gait initiation or termination, are considered as the risk of physical imbalance. Thus, it is essential to develop stability metrics that could assess the safety of wearable robots when encountering gait perturbations.

The Unplanned Gait Termination (UGT) is considered as a gait perturbation in this study. There is a lot of research on UGT without exoskeletons. However, research on UGT with exoskeletons is limited. Therefore, in this study, UGT was induced during assisted walking and the spatiotemporal parameters of wearers were measured using a motion capture system. Then, the effects of assistive algorithms on the stability of wearers during UGT were examined and discussed.

II. UGT Experiment

The experiment was conducted with approval from the Institutional Review Board of Shinshu University (approval number 338).

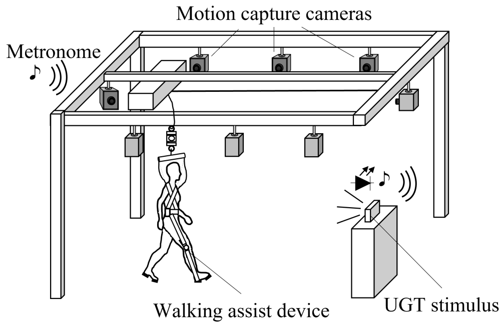

Fig. 1. Overview of UGT experiment environment. The walking lane length was approximately 5 meters.

A. Apparatus

Figure1 shows an overview of the experimental setup. The experimental environment consists of a wearable walking assist robot, metronome, gait termination stimulus device, and motion capture system.

The wearable walking assist robot used in this study is MALO (Motor Actuated Lower-limb Orthosis) [2] which was developed in our laboratory. MALO is equipped with four DC motors that can provide assistance to the wearer's hip and knee joints. The assistance is synchronized with walking by estimating the gait phase based on the timing of heel contact (HC).

The normal walking assist was provided by applying torque in the direction of joint velocity based on biomechanical data obtained during walking [3]. Gait termination stimuli were composed of light and sound and could be triggered at any desired timing based on the gait phase. UGT motions were measured using a motion capture system (MAC 3D system, Motion Analysis Corp.) with 9 cameras installed at a speed of 60 fps.

B. Experiment Protocol

In this study, UGT motions under two conditions, in which gait assistance continued after the UGT stimulus (Assist

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Continue condition) and gait assistance was stopped just after the UGT stimulus (Assist Stop condition) , were recorded and compared. Two young adult males participated in the experiment. Each subject completed a total of 30 trials, consisting of 10 dummy condition trials without UGT stimulus and 10 UGT condition trials that mean Assist Continue and Assist Stop, respectively.

The timing of the gait termination stimulus output was fixed at 1% of the gait cycle based on the study by Ohm et al. [4]. The maximum assistive torques were set to $14\,\mathrm{Nm}$ at the hip joint and $10\,\mathrm{Nm}$ at the knee joint, respectively. The cadence was controlled at $105\,\mathrm{steps/min}$ using a metronome. The experiment was conducted as follows: First, the subjects were fitted with MALO and instructed to walk along the walking lane. The UGT stimuli were presented during walking at the randomized timing. After that, UGT motions were recorded.

C. Data Processing

In this experiment, the completion of gait termination was defined in two ways: First, some parameters were calculated based on the timing of HC of the last leg (forward leg), and the other parameters were calculated based on the time when the forward/backward velocity of the Center of Gravity (COG) became zero or less. According to these definitions, Distance to Terminate Gait (DTG) and Time to Terminate Gait (TTG) were calculated as follows. The HC-based DTG was defined as the forward/backward distance from the HC position of the stance leg when the UGT stimulus occurs (reference leg) to the HC position of the forward leg. The COG-based DTG was defined as the forward/backward distance from the COG position at the stimulus timing to the COG position at the time when the forward/backward velocity of the COG became zero or less. The HC-based TTG was defined as the time from the HC timing of the reference leg to the HC timing of the forward leg. The COG-based TTG was defined as the time from the stimulus timing to the timing when the forward/backward velocity of the COG became zero or less.

Additionally, considering the work of Ohm et al. [3], the difference between the COG-based TTG and the HC-based TTG was defined as the Stabilization Phase.

III. Motions and Parameters During UGT with MALO

In this study, trials with motion capture marker loss were excluded from the analysis. The available trials for each subject were as follows: subject A had 7 in the Assist Continue condition and 6 in the Assist Stop condition, while subject B had 6 in the Assist Continue condition and 3 in the Assist Stop condition. The subsequent analysis was performed using the same number of trials for both subjects.

A. Sequence of UGT Movements

In all recorded UGT movements, UGT proceeded in the following sequence: the HC of the reference leg, the gait termination stimulus presented, the HC of the swing leg (double stance), and the gait termination.

B. Spatio-Temporal Parameters

The spatio-temporal parameters of subject A were as follows, the COG-based DTG was 553 ± 84 mm (mean $\pm$ standard deviation) in the Assist Continue condition and 507 ± 48 mm in the Assist Stop condition. The HC-based DTG was 516 ± 60 mm in the Assist Continue condition and 430 ± 53 mm in the Assist Stop condition. The result suggests that the DTG increased in the Assist Continue condition. The similar tendency was observed in subject B whereas the mean DTG increased by more than $185\,\mathrm{mm}$. Furthermore, the COG-based TTG was 1.16 ± 0.53 s in the Assist Continue condition and 1.06 ± 0.19 s in the Assist Stop condition. The HC-based TTG was 0.52 ± 0.01 s in the Assist Continue condition and 0.51 ± 0.04 s in the Assist Stop condition. Similar to DTG, the mean TTG increased in the Assist Continue condition. The variability of TTG in the Assist Continue condition was larger in the COG base and smaller in the HC base in both subjects.

The Stabilization Phase of each subject was also increased in the Assist Continue condition.

IV. Discussion

The observed sequence of UGT movements in this study is consistent with Hase et al. [5], who observed the UGT without an exoskeleton.

The results of III-B suggest that Assist Continue leads to an increase in DTG both DTG and TTG. In particular, the increase in DTG suggests the possibility that assistive algorithms interfere with safe gait termination. However, it should be noted that the observed differences are small concerning their variability.

Some parts of the increase in COG-based TTG could be described as the effect of the increase in HC-based TTG because HC-based TTG is included in COG-based TTG. However, the increase in the Stabilization Phase suggests that the increase of COG-based TTG could not be completely described as the effect of the increase of HC-based TTG.

Our study suggests the following conclusions. The continued assistance during UGT probably increases the distances and times required for gait termination. However, at least in healthy individuals, the gait assistance, whose torque was less than half of the torque required for normal gait did not significantly change the gait termination movements and stability.

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