様　式　Ｃ－１９、Ｆ－１９－１、Ｚ－１９　（共通）

# 科学研究費助成事業　　研究成果報告書

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研究種目：若手研究
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研究課題名（和文）足関節底屈アシスト時の歩行と筋活動パターンについて

研究課題名（英文）Muscle activation patterns during plantarflexion-assisted walking

研究代表者
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研究成果の概要（和文）：ユーザーの歩行運動学と筋活性がどのように変化するかを理解するために、カスタムなケーブル駆動足関節外骨格を開発した。腓腹筋の筋活動の減少は、外骨格がユーザーの足底屈筋の負荷を部分的に取り除くことができることを示しているが、介助が提供された立脚相の期間におけるより大きな変動は、介助が参加者の歩行を乱し、バランスを維持するために歩行を調整する必要があることを示唆している。このことは、個人差の原因や、足関節外骨格からの補助により良く、より迅速に適応するようにユーザーを指導する方法についての洞察を提供する可能性がある。

研究成果の学術的意義や社会的意義
足関節の屈曲は、歩行時の重心の前方への推進に大きく寄与しており、足関節の屈曲をアシストする足関節外骨格は、歩行の代謝コストを低減することが示されている。しかし、トレーニング期間終了後にしか起こらないことが多く、筋の活性化がどのように適応されるかには大きな個人差がある。本研究は、足関節外骨格による底屈アシストがユーザーの歩行を乱すことを示唆している。ただし、練習を重ねることで、足関節屈曲アシストによる摂動を予測し、歩行を適応させることができるようになるユーザーもいる。ユーザーが外力に対してどのように適応するのかについて理解が深まるにつれ、より効果的な歩行補助装置が期待できる。

研究成果の概要（英文）：A custom cable-driven ankle exoskeleton was developed to understand how users change their gait kinematics and muscle activations. The decrease in gastrocnemius muscle activity indicates that the exoskeleton is able to partially unload the plantar flexor of the participants but larger variations in the period of the stance phase when assistance was provided suggest that the assistance perturbs the participants gait and they would need to adjust their gait to maintain balance. This may provide insights into the causes of individual differences and how to instruct users to adapt to the assistance from an ankle exoskeleton better and more quickly.

研究分野：Human-Machine Interaction

キーワード：ergonomics　gait analysis　motion analysis　electromyography

１．研究開始当初の背景

Although physically assistive devices such as lower-limb exoskeletons are provide the forces required to walk, they are not able to substantially decrease the effort required for walking; the largest decrease in metabolic cost reported thus far is around 20%. This is because walking is largely an unconscious and automated process and user does not necessarily reduce their muscular activity to benefit from the assistive force provided and may adjust their gait, in response to the assistance provided, in ways that are counterproductive. The need to maintain balance while walking, the correlated activation of muscles (muscle synergies), and the perturbation caused by an external force likely have contributed to the ineffectiveness of the assistance provided.

２．研究の目的

In order to improve the effectiveness of assistive devices for walking, there is a need to better understand the mechanisms that prevent users from cooperating with the exoskeleton and reducing their muscular activity. This research aims to shed light on the biomechanical and physiological factors that can cause a user to work against its exoskeleton when walking, leading to increasing metabolic cost. To start-off, how participants modify their gait when an assistive push-off torque based on a pre-defined torque curve is provided.

３．研究の方法

A custom ankle exoskeleton testbed was developed to provide plantarflexion assistance to the participants. As shown in Fig. 1, the attachment to the user's body was developed by modifying a double Krenzak ankle-foot orthosis. Brackets were attached to the sole of the orthosis and the support frames to enable the pulling of a cable to produce an ankle flexion force. In addition, the exoskeleton was instrumented with miniature tensile sensors, encoders, and footswitches to measure the assistive force provided, the ankle angle, and the gait cycle. These ankle exoskeletons were actuated by a pair of off-board brushless motors connected via Bowden cables. The magnitude and timing of the assistive force provided could be customized based information from the sensors on the ankle exoskeleton.

Participants were instructed to walk on a treadmill at 1.0 m $s^{-1}$ with the ankle exoskeleton. Plantarflexion assistance was provided based on a pre-defined torque curve with peak torque occurring at about 48% of the gait cycle (starting from the heel contact event). Participants walked with plantarflexion assistance for five trials that lasted for 5 minutes of with 2 minutes rest in between trials.

The kinematic data were collected using a 3D motion capture system consisting of 9 infrared cameras tracking reflective markers attached to the bony landmarks of the participant. Additionally, the muscle activities of the rectus femoris, biceps femoris, tibialis anterior, and gastrocnemius of the right leg of the participant were measured using wireless surface electromyogram (sEMG) electrodes. Muscle

activity was normalized to that measured when walking without assistance (while wearing the ankle exoskeleton)

Fig. 1. Ankle exoskeleton

Fig. 2. Experiment scene

４．研究成果

Variations in the period of the stance phase were greater when plantar flexion assistance was applied compared to walking without assistance. A trend of decreasing variation in the period of the stance phases participants could be observed as we go from the first to the fifth trial. A similar trend of decreasing variation in ankle plantarflexion/dorsiflexion range of motion (RoM) could also be observed. Although the muscle activity of the gastrocnemius is lower when walking with plantarflexion assistance than when walking without assistance, no change in muscle activity was observed. The larger variations in the period of the stance phase when assistance was provided suggest that the assistance perturbs the participants gait and they would need to adjust their gait to maintain balance. The decreasing trend in variations in the period of the stance phase and ankle RoM suggests that participants gradually adapt their gait so that the effect of perturbation from assistance is minimized. The decrease in gastrocnemius muscle activity indicates that the exoskeleton is able to partially unload the plantar flexor of the participants, but the lack of decrease in the 5 trials suggests a total 25 minutes may not have been sufficient for the participants to optimize their gait to the assistance. More participants and more practice trials are needed to account for individual differences and to verify these effects.

国際学会発表

Wen Liang Yeoh, Fukuda Osamu, Nobuhiko Yamaguchi, Hiroshi Okumura, Satoshi Muraki. Gait Adaptations to Plantarflexion Assistance Based on Predefined Torque Trajectories, IEA2024, the 22nd Triennial Congress of the International Ergonomics Association. (Accepted and to be presented in August 2024)

５．主な発表論文等

〔雑誌論文〕　計3件（うち査読付論文　3件／うち国際共著　3件／うちオープンアクセス　1件）

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| １．著者名<br>Yeoh Wen Liang、Choi Jeewon、Loh Ping Yeap、Fukuda Osamu、Muraki Satoshi | ４．巻<br>35 |
| ２．論文標題<br>Motor Characteristics of Human Adaptations to External Assistive Forces | ５．発行年<br>2023年 |
| ３．雑誌名<br>Journal of Robotics and Mechatronics | ６．最初と最後の頁<br>547～555 |
| 掲載論文のDOI（デジタルオブジェクト識別子）<br>10.20965/jrm.2023.p0547 | 査読の有無<br>有 |
| オープンアクセス<br>オープンアクセスとしている（また、その予定である） | 国際共著<br>該当する |

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| １．著者名<br>Yeoh Wen Liang、Miyata Ryosuke、Fukuda Osamu、Yamaguchi Nobuhiko、Okumura Hiroshi | ４．巻<br>- |
| ２．論文標題<br>Development of a person-following robotic assist walker with compliant-control arbitrated role-switching | ５．発行年<br>2023年 |
| ３．雑誌名<br>Artificial Life and Robotics | ６．最初と最後の頁<br>1-7 |
| 掲載論文のDOI（デジタルオブジェクト識別子）<br>10.1007/s10015-023-00864-0 | 査読の有無<br>有 |
| オープンアクセス<br>オープンアクセスではない、又はオープンアクセスが困難 | 国際共著<br>該当する |

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| １．著者名<br>Yeoh Wen Liang、Choi Jeewon、Loh Ping Yeap、Saito Seiji、Muraki Satoshi | ４．巻<br>- |
| ２．論文標題<br>Users’ adaptations to the proportional speed control of a motorised walker | ５．発行年<br>2021年 |
| ３．雑誌名<br>Disability and Rehabilitation: Assistive Technology | ６．最初と最後の頁<br>1～10 |
| 掲載論文のDOI（デジタルオブジェクト識別子）<br>10.1080/17483107.2021.2017031 | 査読の有無<br>有 |
| オープンアクセス<br>オープンアクセスではない、又はオープンアクセスが困難 | 国際共著<br>該当する |

〔学会発表〕　計1件（うち招待講演　0件／うち国際学会　1件）

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| １．発表者名<br>Wen Liang Yeoh, Fukuda Osamu, Nobuhiko Yamaguchi, Hiroshi Okumura, Satoshi Muraki |
| ２．発表標題<br>Gait Adaptations to Plantarflexion Assistance Based on Predefined Torque Trajectories |
| ３．学会等名<br>, IEA2024, the 22nd Triennial Congress of the International Ergonomics Association（国際学会） |
| ４．発表年<br>2024年 |

〔図書〕　計0件

〔産業財産権〕

〔その他〕

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６．研究組織

| | 氏名<br>（ローマ字氏名）<br>（研究者番号） | 所属研究機関・部局・職<br>（機関番号） | 備考 |
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７．科研費を使用して開催した国際研究集会

〔国際研究集会〕　計0件

８．本研究に関連して実施した国際共同研究の実施状況

| 共同研究相手国 | 相手方研究機関 |
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