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論文審査の結果の要旨および担当者

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論　文　題　目

Gait analysis of the reaction motions against muscle restriction for the purpose of reproducing the gait of the elderly in the young
(若年者による高齢者の歩行動作の模擬再生を目的とした筋力抑制に対する反応動作の歩行解析)

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論文審査の結果の要旨

The overall aim of this doctoral project is the investigation and validation of Muscle Activity Restriction Taping Technique (MARTT), a technique proposed by the author of this project, that could serve to ease the understanding and the study of age-related changes in the elderly gait by utilizing young individuals to take the place of the elderly with the main objective of preventing the exposure of the older adults to exhausting and dangerous experimental conditions that the realization of such studies might imply. In addition, this project aims to investigate how the human body compensates muscle weakness during walking and for what purpose.

Chapter 1 introduces the social background of this project and the importance of assisting the elderly gait in order to maintain in this population a healthy mobility level that is necessary to guarantee a good quality of life. In order to assist the elderly gait, the understanding of their gait impairments under different activities and terrain conditions is essential. This chapter includes the state of the art on the elderly age-related gait impairments and joint compensation motions that are the result of the gait alterations in the elderly. This chapter also describes existing age simulation suits that constitute a method for young individuals to feel what it is to be in the body of an older person and to get conscious about the elderly needs.

As described in Chapter 1, the elderly gait encompasses several disorders, including a lower minimum toe clearance (MTC) to the ground, which is a potential cause of tripping and falling while walking. Devices that assist in maintaining a safe MTC while the elderly walk could reduce such risks. However, the testing and development processes of such devices require experimental trials in conditions that imply high injury risks for the older population. Thus, the participation of the elderly in these processes to find effective assistance methods may jeopardize their safety. To avoid this issue, young individuals could substitute the elderly in the initial experimental process. In this regard, the author of this doctoral project proposed MARTT as a method to reproduce the lower MTC of the elderly in young adults, by applying this technique to the lower-limb to cause a muscle weakening effect.

Chapter 2 covers the validation of MARTT as a technique that is able to reduce the MTC of young adults to that of the elderly. In total 10 male subjects participated in this study, and the walking trials were carried out on a treadmill. By the means of MARTT, two different muscle restriction approaches were studied at two different walking speeds. One approach restricted muscles at the shank and the other restricted simultaneously muscles at the shank and thigh. One walking speed corresponded to 3.5 km/h, considered as the average speed for young adults, and the second walking speed corresponded to 4 km/h, regarded as the average speed for older adults. In the two mentioned approaches and walking speeds, the MTC of the young subjects was reduced to a median value lower than 10.1 mm, which is within the range of the MTC values reported for the elderly in literature, that is about 7 – 13 mm. The reduction of the MTC significantly increased the foot-ground contacts during the swing phase of the young subjects. Foot-ground contacts constitute a major cause of tripping and falling in older adults. The foot-ground contact frequency was more than twice as that in normal walking (natural walking of the subjects without the restriction applied by MARTT) when the shank muscles were restricted, and more than five times when both the shank and thigh muscles were restricted. In addition, MARTT reproduced in the young subjects spatio-temporal parameters that characterize the elderly gait, which are: reduced period of the single support phase and shorter step length.

Moreover, the loss of muscle mass with aging and the consequent muscle weakness results in compensatory body motions during walking. Although these compensatory motions increase the cost of walking, they appear to be an attempt by the elderly to maintain a safe ambulation, as suggested in studies about the elderly gait. However, the relationship between the affected muscles, that perceive a certain level of weakness, and compensatory body motions along the gait cycle needs elucidation. Similarly, the purpose of the compensatory motions and the gait characteristics during walking that the human body prioritizes to compensate need to be investigated.

Chapter 3 describes the examination of the gait compensation strategies of the young subjects when walking with MARTT. The lower-limb showed an active kinematic compensation chain, in which joints that perceived no or less restriction compensated for the most compromised joint to prevent foot drop, knee hyperextension

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in the terminal stance phase, and knee hyperflexion in the loading response phase, and to maintain the step length. In addition, joints could compensate for themselves when the muscles acting on the other joints were unable to assist, as observed on the ankle joint that compensated for itself to prevent foot drop when the knee and hip flexor muscles were restricted. The observed compensation strategies agreed with a previously reported computational simulation about gait compensations appearing as consequence of muscle weakness. To add, similarities with the compensation strategies reported for the elderly were found.

Chapter 4 encompasses a discussion about the application of MARTT in the study of the elderly gait and how this technique could be useful to find out effective gait assistive methods and test assistive devices in the young until the control strategies of such devices are mature and safe enough to be tested in the elderly. This chapter also discusses about the possibility of combining MARTT with existing age simulation suits to reproduce in the young not only the lower MTC and joint compensation strategies seen in the elderly as a result of muscle weakness, but also other afflictions, such as sensory impairments and the reduced joint range of motion. Additionally, this chapter includes a discussion on the limitations of MARTT in relation to the reproduction of the elderly gait characteristics in the young, and also a discussion on the limitations and justifications of the experimental trials that have been conducted for the purpose of this doctoral project.

Chapter 5 concludes this doctoral thesis highlighting the main findings on the study about the validation of MARTT, that is the focus of Chapter 2, and on the study about the biomechanical analysis of gait compensation strategies, that is the focus of Chapter 3. In addition, the future directions of this project, proposed by the author of this thesis, are listed in this chapter.

To conclude, this doctoral project has validated MARTT and has studied the compensation motions at the lower limb that result from muscle weakness. The results of this project provide insights on how to implement MARTT, its applicability and limitations, and also insights on joint compensations that appear with the deterioration of gait ability. Further studies should include the examination of the compensation strategies and classification proposed in this project in a larger number of young subjects, the analysis of the compensations at the upper body, and the comparison of electromyography data of the young walking with MARTT with that of the elderly.

以上のように本論文ではMARTTデバイスを用いて若年者を被験者として高齢者の歩容を再現し，下肢の筋力衰弱時の代償的歩行戦略を明らかにしている。これらの評価方法並びに得られた結果は、加齢に伴う歩容変化のさらなる理解および高齢者の効果的な歩行支援方策の開発への応用を実現するために重要であり、工学の発展に寄与するところが大きいと判断できる。よって、本論文の提出者であるJessica Gabriela Beltran Ullauri君は博士（工学）の学位を受けるに十分な資格があると判断した。