論文 / 著書情報
Article / Book Information

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Title(English)	DEVELOPMENT AND EVALUATION OF A GAIT-ASSIST WEARABLE ROBOT USING INTERACTIVE RHYTHMIC STIMULATION TO THE UPPER AND LOWER LIMBS
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（博士課程）
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論 文 要 旨
THESIS SUMMARY

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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

Many power-assist wearable exoskeletons have been developed to provide walking support and gait rehabilitation for elderly subjects and gait disorder patients. Most designers have focused on a direct power-assist to the wearer's lower limbs. However, gait is a coordinated rhythmic movement of four limbs controlled intrinsically by central pattern generators, with the upper limbs playing an important role in walking. Maintaining a normal gait can become difficult as a person ages, because of decreases in limb coordination, stride length, and gait speed. It is known that coordination mechanisms can be governed by the principle of mutual entrainment, in which synchronization develops through the interaction between nonlinear phase oscillators in biological systems. This principle led us to hypothesize that interactive rhythmic stimulation to upper and lower limb movements might compensate for the age-related decline in coordination, thereby improving the gait in the elderly. To investigate this hypothesis, we developed a gait-assist wearable exoskeleton that employs interactive rhythmic stimulation to the upper and lower limbs based on the mutual entrainment principle to provide coordination to the upper and lower limbs.

In particular, we investigated the effect of stimulation to the upper and lower limbs on spatial gait parameters (i.e., shoulder- and hip-joint amplitude), their corresponding coefficient of variance (*CV*s), and upper–lower–limbs' coordination by conducting walking experiments with 5 healthy elderly subjects under a non-assist and assist condition, where the output motor torque was applied at a 15% lag time between the foot contact timing and upper-limb motors. The results showed a significant increase in the mean right shoulder- and hip-joint amplitude, with a mean increment of about 63% and 12.5%, respectively between the non-assist and assist conditions. In addition, the results showed a symmetrical pattern in the right upper–lower–limbs' coordination between the non-assist and assist conditions. However, the results showed a significant increase in the *CV* of the right shoulder- and hip-joint amplitude with an elderly subject between the non-assist and assist conditions. Although the results indicate that interactive rhythmic stimulation to the upper and lower limbs significantly increases the shoulder- and hip-joint amplitude without adversely affecting the upper–lower–limbs' coordination, the results indicate an increase in the *CV* of the shoulder- and hip-joint amplitude for the elderly. We speculate that the increase in gait variability might be attributed to the heavy weight of the lower limb motors, and a direct stimulation to the wearer's lower limbs, which might cause gait instability for the elderly.

To overcome the aforementioned limitations, we next developed a gait-assist wearable exoskeleton using interactive rhythmic stimulation to the upper limbs based on the mutual entrainment principle in human-robot interaction, and upper–lower–limbs' neural coupling in human locomotion. We investigated the effect of stimulation to the upper limbs on a spatial (i.e., hip-swing amplitude) and temporal (i.e., hip-swing period) gait parameter, their corresponding *CV*s, and upper–lower–limbs' coordination by conducting walking experiments with 12 elderly subjects under one control condition and five upper-limb-assist conditions, where the output motor torque was applied at five different upper-limb swing positions. Here, the swing position corresponds to the arm position with respect to the rearmost position at 0%, 10%, 20%, 30%, and 40% lag times. The results showed a statistically significant increase in the mean hip-swing amplitude, with a mean increment of about 7% between the control and upper-limb-assist conditions at all lag times. They also showed a statistically significant decrease in the mean hip-swing period, with a mean decrement of about 2.3% between the control and the upper-limb-assist condition at 40% lag time. In addition, the results showed a symmetrical pattern in the left and right upper–lower–limbs' coordination between the free and upper-limb-assist conditions at all lag times. Further, the results showed no statistically significant difference in the mean *CV*s of the hip-swing amplitude and period between the free and upper-limb-assist conditions at all lag times. Although no stimulations were applied to the lower limbs, the results indicate that stimulation to the upper limbs statistically significantly increases the hip-swing amplitude and gait speed, without adversely affecting the elderly's gait stability, and upper–lower–limbs' coordination. Hence, the results indicate that interactive rhythmic stimulation to the upper limbs at an optimal condition could offer a promising neurorehabilitation strategy for the elderly's gait.