The Effect of Ergonomic Fit on Walking Performance of a Gait-Assist Wearable Robot

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Introduction

According to the World Health Organization (WHO) (Bull et al., 2020), a lack of physical activity likely increases the risk of chronic diseases; Thus, it is important to regularly participate in physical activity in order to maintain a healthy lifestyle. Among the various types of physical activity, walking is an exercise that is easily accessible and can be enjoyed by all ages and genders in everyday settings (Feodoroff & Blümer, 2022). While proper walking positively contributes to people's health, a deviation from normal gait tends to decrease mobility, thus affecting one's safety (Waters & Mulroy, 1999). Mikolajczyk et al. (2018) affirmed that functional recovery and support for those with abnormal gait are critical for improving their quality of life. To this end, recent developments of gait-assist wearable robots are on the surge as a novel means to support the gait rehabilitation of patients. However, when the wearability of such assistive devices is not satisfied, the intended functionality of the devices cannot be experienced by the users (Walsh, 2018). Particularly, in the context of gait-assist wearable robots, dynamic wearability must be considered. Gemperle et al. (1998) defined it as the interaction between the wearable object and the human body in motion, and proposed design guidelines for wearability including proper placement, humanistic form factor, movement, size perception, various sizing and attachment, many of which are related to ergonomic fit. Given so, in this paper, we aimed to investigate the effect of an ergonomic fit on the walking performance of a commercial gait-assist wearable robot, under the two different exercise modes. The first exercise mode, called the Aqua mode, was intended to impose resistance on the legs, thus having users walk with more force. On the other hand, the second exercise mode, called the Boost mode, was designed to provide support while lifting and lowering the legs, thus allowing users to walk with less force.

Methods

We conducted an experimental study with 12 participants of both genders (N=12, 7 men and 5 women) in their 30s; and did not have any chronic musculoskeletal or neurological complications at the time of data collection. The mean age of the participants was 32.08 years old (SD 2.50). The gait-assist wearable robot examined in this study was designed to be worn on the waist and pelvis, wrapped with a band above the knee. Prior to participating in the actual walking experiment, we overviewed with the study participants the research procedures and voluntary nature of this study, and offered them to review and sign the consent, approved by the participating university's IRB office (No. 2209/002-025).

Upon agreement, the participants walked on a force-plate embedded treadmill (Zebris® Medical GmbH, Germany) at 4 - 5 km/h speed (4.27 ± 0.21 km/h) for 20 minutes (Fig. 1A) at the three walking conditions, wearing the robot: a) with no exercise mode on (C1), b) with the Aqua mode on (C2) and c) with the Boost mode on (C3). We also collected the data when the participants were wearing regular exercise clothes (no robot wearing) as a baseline (C0). During the walking exercise, we measured the participant's gait parameters such as the foot force, foot pressure, foot rotation, stride length and cadence, as well as critical biomarkers (e.g., heart rates) in real-time, and compared the data across the aforementioned wearing conditions. We also examined the participants' walking performance by comparing the data between those with a proper fit vs. those with an improper fit.

Results

The results indicated that the participants' heart rates were from the highest to lowest in the following order: C2 > C1 > C3 > C0 (p = .00). It means that more energy was consumed during the Aqua mode than the other walking conditions, in which resistance was added to gait motion. The foot force and pressure in the stance phase during walking increased in the following order: C0 > C1 > C2 > C3 (p = .00) (Fig. 1B, 1C). The result signified that the participants experienced decreased force and pressure on their feet while walking with the wearable robot, regardless of the exercise modes. Furthermore, the trends in the foot force and pressure at walking were more noticeable in those with an improper fit of the wearable robot, as compared to those with a proper fit (p = .00). From the result, we could infer that when the fit is not satisfactory, the higher ground reaction force was required to keep balance on feet.

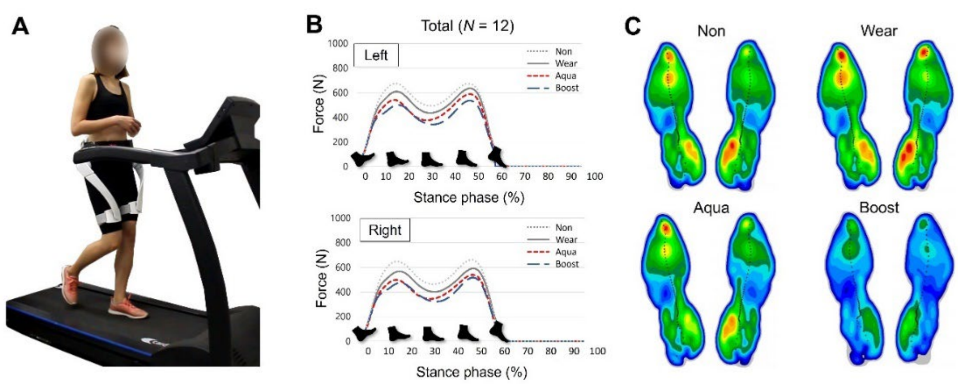

Fig. 1. Gait analysis: A. gait-assist wearable robot, B. force and C. pressure differences

Additionally, the foot rotation was the largest at C1, followed by C3 > C0 ≈ C2. The increase in foot rotation of participants with an improper fit was much larger than those with a proper fit (20.36 to 48.21% vs. 4.00 to 12.79%), which indicated that when participants experienced an unsatisfactory fit of the wearable robot on their body, they tended to correct their gait by giving larger foot rotation than the other case. Moreover, the highest stride length was found at C2, whereas the cadence (steps/min) was the largest at C0. This result was more prominent when a proper fit was observed. Namely, the stride length for participants with a proper fit tended to increase more than those with an improper fit in the Aqua mode when resistance was added (5.24% vs. 3.75%). On the other hand, the cadence of those with proper fit tended to decrease more than those with an improper fit in the same mode (-5.84% vs. -1.68%). These results mean that the exercise mode of the wearable robot was significantly more effective when it was worn with a proper fit, as compared to the opposite case with an improper fit.

Discussions & Conclusion

The results of this study suggested that achieving a satisfactory ergonomic fit is essential to provide the wearers with the intended functionality and satisfactory wearability of wearable robotic devices. However, this study has some limitations in evaluating short-term wearing for a few people with a normal gait. In the future, we plan to extend this study to the effects of long-term wearing of the gait-assist wearable robot on people with abnormal gait. The findings are particularly meaningful in that the lessons gained from this study alert the manufacturing industry of wearable robots to the importance of ergonomic fit considerations, along with technological advancement in engineering components. We hope these insights will help fulfill the urgent needs of the growing global wearable robotics market.

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