Time-Efficient Protocol for Personalizing Hip Exoskeleton Assistance Using a Respiratory Kinetics

Hyunho Jeong and Sukyung Park
Department of Mechanical Engineering, KAIST, Daejeon, Republic of Korea
Email: hyunho.jeong@kaist.ac.kr

SUMMARY

This study proposes an evaluation protocol that rapidly personalizes the intensities of hip flexion and extension assistance during walking by leveraging respiratory response kinetics. An experiment was conducted on eight healthy adult males wearing a hip exoskeleton to compare the proposed protocol against a conventional proccesure that relies on reaching a steady-state respiration. The results showed that the proposed protocol reduced the overall experimental time by more than 80%, while maintaining a error of 8.83 ± 3.59% in metabolic cost. Additionally, an effectiveness of flexion or extension assistance on metabolic cost reduction (up to 25.6%) differed across individuals, underscoring the necessity of personalizing hip exoskeleton assistance strategies.

INTRODUCTION

Measuring metabolic cost via respiratory gas analysis is commonly employed to evaluate exoskeleton assistance performance. However, the proccesure can become extremely time-consuming, particularly when multi-dimensional assistance parameters must be optimized. Although a continuous sweep protocol leveraging respiratory response kinetics has been proposed[1, 2], it was limited to a single assistance variable. In this study, we propose a metabolic cost evaluation protocol that rapidly screens the intensities of hip flexion and extension assistance and derives an individualized optimal assistance strategy.

METHODS

Eight healthy adult males participated in the experiment, each visiting the laboratory over three days (Fig. 1A). On the first visit, participants underwent walking training to acclimate to the hip exoskeleton (H10, Angel Robotics). On the second and third visits, they were randomly assigned to either a discrete grid protocol or a continuous line-search protocol while walking on a treadmill at 1.5 m/s (Fig. 1B). In the discrete grid protocol, the metabolic cost was determined by averaging the respiratory gas consumption over the final two minutes of a five-minute assisted walking. The maximum flexion and extension assistance moments were set to 0.4, 0.11, 0.18 Nm/kg, resulting in a total of nine (3×3) conditions. In contrast, in the continuous line-search protocol, the assistance moment was varied over 10 minutes, following a path that traversed all nine of the aforementioned conditions (Fig. 1B). The metabolic cost under tow assistance variables was modeled with a second-order polynomial, and the coefficients were determined via instantaneous cost mapping (ICM) [2].

RESULTS AND DISCUSSION

When measuring the metabolic cost of each hip assistance strategy using the discrete grid protocol, it took 45 minutes in total (excluding rest), whereas the continuous line-search protocol yielded comparable data in only 10 minutes. A comparison of the metabolic cost measurements from the two protocols showed that the continuous line-search protocol had a mean absolute percentage error (MAPE) of 8.83 ± 3.59%. This value did not significantly differ from the 6.35 ± 2.53% error observed in inter-visit metabolic cost variations of non-assisted walking ($p=0.32$), indicating that employing ICM with gradual changes in the assistance level sufficiently compensates the respiratory response lag.

Moreover, the proposed method enabled the identification distinct effective assistance strategies for each individual. A multiple regression analysis of the metabolic cost obtained from the discrete grid protocol revealed that among the eight participants, five showed a significant reduction in metabolic cost only under flexion or extension assistance. Furthermore, 80% of the significant assistance strategies identified by both protocols were identical, indicating that the optimal assistance varies among individuals, and that the continuous line-search protocol can swiftly capture these differences.

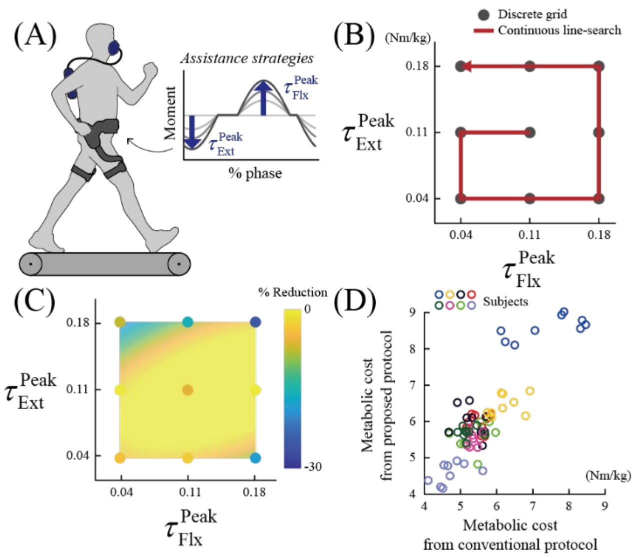

Figure 1 (A) Experiment setup (B) Assistance profile of the hip exoskeleton (C) Metabolic cost of a representative subject (D) Scatter plot of two protocols' evaluation result.

CONCLUSIONS

This study proposed a method that significantly reduces the time required for metabolic cost evaluation experiments intended to personalize hip exoskeleton flexion and extension assistance. We confirmed that the individualized assistance strategies derived through this approach exhibit high consistency with results from the conventional evaluation method. This finding suggests that leveraging a physiology-based protocol design can effectively lower the cost of exoskeleton personalization while enhancing its performance. Moreover, because the motion and metabolic cost were collected under a continuous range of assistance intensities, they can be expected to offer strong generalization performance when utilized in data-driven approaches.

ACKNOWLEDGEMENTS

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REFERENCES

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[2] Malcolm et. al., JNER 14, no. 1, 2017.