# **Report on the paper.**

Your paper has been extensively reviewed. Reviewers showed interest in your work but a revision is needed to. Please complete the SoA since now importing references are missing; make a thorough grammatical revision and let a native speaker read and correct your manuscript;

and

make explicit what was the contribution of this manuscript compared to your previous publication. Only when this is done and the other comments of the reviewers are addressed satisfactory the manuscript can be considered for publication.

## **Reviewer 1 (review 34623)**

**Main contributions**

Demonstration that Pneumatic Gel Muscle actuators triggered by stance contact forces can be used to assist hip extension during gait in healthy subjects, as shown by a statistically signicant decrease in maximum voluntary contraction of the majority of 8 major lower limb muscles in the majority of the test subjects.

**Prior art**

The significance of this paper is explained as being to overcome the gap that existing wearable lower limb support devices fail to simultaneously fulfill the criteria of a "wearable, lightweight, portable, easy to use and muscle fatigue reducing" device. This is supported by the examples of the HAL, Wearable agri robot, Walking Assist Device, Roboknee and Malcolm et al.'s pneumatic exoskeleton. However, there are additional assistive devices that should be considered in the literature review due to their relevancy to the gap and key contribution of this paper:

[1] B. T. Quinlivan *et al.*, “Assistance magnitude versus metabolic cost reductions for a tethered multiarticular soft exosuit,” *Sci. Robot.*, vol. 2, no. 2, p. eaah4416, 2017.

[2] A. T. Asbeck, S. M. M. De Rossi, K. G. Holt, and C. J. Walsh, “A biologically inspired soft exosuit for walking assistance,” *Int. J. Rob. Res.*, vol. 34, no. 6, pp. 744–762, 2015.

[3] A. T. Asbeck, K. Schmidt, and C. J. Walsh, “Soft exosuit for hip assistance,” *Rob. Auton. Syst.*, vol. 73, pp. 102–110, 2015.

[4] K. Schmidt *et al.*, “The myosuit: Bi-articular anti-gravity exosuit that reduces hip extensor activity in sitting transfers,” *Front. Neurorobot.*, vol. 11, no. OCT, pp. 1–16, 2017.

[5] L. N. Awad *et al.*, “A soft robotic exosuit improves walking in patients after stroke,” *Sci. Transl. Med.*, vol. 9, no. 400, 2017.

[6] S. H. Collins, M. B. Wiggin, and G. S. Sawicki, “Reducing the energy cost of human walking using an unpowered exoskeleton,” *Nature*, vol. 522, no. 7555, pp. 212–215, 2015.

[7] S. Sridar, P. H. Nguyen, M. Zhu, Q. P. Lam, and P. Polygerinos, “Development of a soft-inflatable exosuit for knee rehabilitation,” *IEEE Int. Conf. Intell. Robot. Syst.*, vol. 2017–Septe, pp. 3722–3727, 2017.

* A tethered bilateral hip extension and plantarflexion (biarticular) exosuit that reduced metabolic rate of gait by 22.8 % when the suit assisted compared to when it was off (but still worn). The suit could be powered with a body worn actuation unit for a complete untethered weight of 6 kg, but it was not reported whether this would result in a reduction in metabolic cost compared to the suit being off or not worn at all. [1]

Quinlivan, B.T., Lee, S., Malcolm, P., Rossi, D.M., Grimmer, M., Siviy, C., Karavas, N., Wagner, D., Asbeck, A., Galiana, I. and Walsh, C.J., 2017. Assistance magnitude versus metabolic cost reductions for a tethered multiarticular soft exosuit. Science Robotics, 2(2), pp.eaah4416-eaah4416.

* A 7.57 kg untethered bilateral hip extension and plantarflexion (biarticular) exosuit that provided 30 % of the biological torque moment for gait. The effect of the suit on metabolic rate or EMG magnitude during walking was not reported.[2][3]

Asbeck, A.T., Schmidt, K. and Walsh, C.J., 2015. Soft exosuit for hip assistance. Robotics and Autonomous Systems, 73, pp.102-110.

* A 4.6 kg untethered bilateral hip and knee extension (biarticular) exosuit that provides 26 % of the biological knee extension torques during sit-to-stand to reduce hip extension EMG activity in such movements.[4]

Schmidt, K., Duarte, J.E., Grimmer, M., Sancho-Puchades, A., Wei, H., Easthope, C.S. and Riener, R., 2017. The Myosuit: Bi-articular anti-gravity exosuit that reduces hip extensor activity in sitting transfers. Frontiers in neurorobotics, 11.

* A 4.1 kg untethered unilateral ankle plantar/dorsiflexion exosuit that reduced metabolic rate of gait by 16.3 % when the suit assisted compared to when it was off (but still worn). The metabolic rate of when the suit assisted compared to when it was not worn was not reported.

Awad, L.N., Bae, J., O壇onnell, K., De Rossi, S.M., Hendron, K., Sloot, L.H., Kudzia, P., Allen, S., Holt, K.G., Ellis, T.D. and Walsh, C.J., 2017. A soft robotic exosuit improves walking in patients after stroke. Science translational medicine, 9(400), p.eaai9084. [5]

* A 0.5 kg untethered passive bilateral ankle plantarflexion exoskeleton that reduced metabolic rate of gait by 7 % when worn compared to when not worn.[6]

Collins, S.H., Wiggin, M.B. and Sawicki, G.S., 2015. Reducing the energy cost of human walking using an unpowered exoskeleton. Nature, 522(7555), p.212.

Given these additional devices, the novelty of your key contribution stands, as while some of the portable versions of the above devices could potentially reduce muscle activity during gait compared to when they are not worn, this situation is not reported (whereas you have reported a reduction in muscle activity). This assumes the device is active, as compared to Collins et al.'s passive device, which reduced muscle activity compared to the unworn state.

Your literature review should account for at least some of the above references and in the gap and contribution of the paper you should emphasise that you have shown muscle activity reduction during gait of the suit in the worn compared to the unworn state (instead of the worn but "off" state).

**Paper strengths and weaknesses**

Overall, the paper is reasonably clear in terms of English language use, logical structuring of ideas and presentation of figures. The methodology of the experiments and analysis appears sound. Some improvements can be made to make the paper easier to understand. This includes minor language corrections and making sure the text in the figures is not too small. These details are outlined in the comments in the attached pdf.

In summary, the paper has a good foundation and is reasonably easy to follow. It can be improved primarily by adding references that support the state-of-the-art in exoskeletons and exosuits that reduce muscle fatigue or metabolic cost.

## **Reviewer 2 (review 34625)**

This paper presents an assistive wearable device for walking tasks (called by the authors Augment Walking Suit, or AWS). The system uses a novel type of pneumatic actuation called Pneumatic Gel Muscle (PGM), already described in a previous publication from the same authors. The presented system uses active actuation, which differentiates it from their previous works. The paper contains also an experimental validation of the system with a small group of subjects, showing statistical indications of reduction of the muscular activity.

**As a general comment,**

The presentation of the paper should be improved with a thorough revision of the writing. Apart from this aspect, the paper is in general well structured. The introduction should be improved in several aspects. The authors mix different kind of exoskeletons in the state-of-the-art. I would suggest to focus on walking assistive exoskeletons. Industrial exoskeletons are usually not focused on walking, so the inclusion of them is a bit confusing. A better organization of the introduction would help to follow the reasoning.

Evaluating the system with only 5 subjects is probably not enough to demonstrate statistically the effectiveness of the system. However, at least there is some good indication of it. Did the authors consider the use of more than one pressure sensor? Using also a pressure sensor on the front of the foot, would allow to detect also the toe-off. It could be possible to use IMUs to measure the motion and use it in the control.

Maybe the authors could report also the weight of the system. Also subjective opinions from the users would be interesting, to know more about comfort and wearability. This will give more importance to the soft aspect of the system.

Table I has too many information. Maybe it could help to use some colors to indicate the more significant values.

**I have also a few minor comments:**

* Several acronyms are not properly defined (PAM, AWS, etc);
* The figure captions should be more explanatory, in particular figures 1, 2, 3, 4, 5, 6, 7, 8 and 9;
* The figures should be referenced using always the same format, for example "Fig.";
* Equation (2) has two ";" between the polynomial and the R value.
* Figures 2 and 4 use different units for the pressure. Please, use the same one for clarity;
* Figure 5 is difficult to understand. I would suggest to use a more standard gate figure;
* Table I should have the caption on the top and not at the bottom.

## **Reviewer 3 (review 36917)**

This work presents the integration of a soft walking suit with a control scheme utilizing a portable electro-pneumatic system. Pneumatic gel muscles are utilized to provide assistance to the relevant muscle groups during walking. A detailed electromyographic analysis of a set of muscle groups is performed to show efficacy of the walking suit.

**General Comments:**

-The authors do not clearly mention where the walking suit assists during walking (i.e. the swing phase which is clear from the accompanying video.).

-Contributions of this work as compared to previous literature should be clearly specified in the introduction.

-Prior literature on soft assistive devices for similar applications are not cited. For example:

Wehner et al. "A lightweight soft exosuit for gait assistance.", Sridar et al. "Development of a soft-inflatable exosuit for knee rehabilitation.", [7]

Asbeck et al. "A biologically inspired soft exosuit for walking assistance."[2]

-The design of the walking suit is not presented.

-Fig. 10: The data from the left and right FSR for all participants looks very similar. Please verify this. This figure is also not cited in the text.

-The results are not explained clearly. More clarification is required in the discussion section pertaining to the percentage reduction in muscle activity.

-Standard deviation for the data in Fig. 4 is not provided.

-Acronyms must be defined in the test prior to using them ex: AWS, TA etc.

-Thorough grammatical revision and proofreading is required.