

The SoftFoot Pro: an Anthropomorphic and Adaptive Soft Articulated Prosthetic Foot

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This file contains all reviewer reports in order by version, followed by all author rebuttals in order by version.

Attachments originally included by the reviewers as part of their assessment can be found at the end of this file.

Version 0:

Reviewer comments:

Reviewer #1

(Remarks to the Author)

Comments

The manuscript titled “The SoftFoot Pro: an Anthropomorphic and Adaptive Soft Robotic Prosthetic Foot” presents a novel approach to prosthetic foot design, particularly in its anthropomorphic and adaptive characteristics. However, the following comments and queries are raised for consideration:

1. Theoretical formulations are essential for understanding the various mechanical behaviours of the prosthetic foot. The current manuscript presents only experimental results. Additionally, the measurement procedures are not described in the Methods section, which would aid reader comprehension and reproducibility.
2. The theoretical modelling of the sole’s mechanism is not provided. It is unclear how the individual links were designed specifically for this prosthetic foot.
3. No design calculations are included, particularly regarding the selection of spring stiffness, which is crucial for performance.
4. If the sole is described as flexible, how can it simultaneously be inextensible? This apparent contradiction needs to be clarified.
5. How was the stability of the prosthetic foot evaluated? Information on assessment methods is lacking.
6. What is the functional role of links 7 and 8? They appear to serve primarily aesthetic purposes, and their contribution to the overall mechanism should be clarified.

Reviewer #2

(Remarks to the Author)

This paper presents the new design of a unique prosthetic foot/ankle called the SoftFoot Pro. The device’s distinctive design features a flexible, inextensible artificial tendon that mimics the plantar fascia of the foot and toe. This allows the foot to adapt to uneven terrain, similar to a human foot. By achieving biomimetic adaptation to diverse surfaces, the authors hope that the foot will facilitate biomimetic movement in the contralateral limb and other body parts.

I believe that the core concept motivating this design is sound and could enhance ambulation for users. However, I have significant concerns about how the information is presented and compared here, as well as the conclusions that the authors draw from the experimental data.

Major Comments

Major Comment 1:

It is not clearly explained why there are two different designs presented in this paper: the Main Study and the Preliminary Study. The differences between the two foot designs are briefly discussed and illustrated in a figure, but the authors do not address the functional differences between the feet or the reason for the redesign. Moreover, it is confusing and challenging for the reader to go through the results of the preliminary study in the supplementary material and then compare them to the results of the main study in the main text. I would offer two suggestions: 1) If the two feet are functionally similar in performance, combine the results of both participants into one set of results and discuss why the feet are functionally similar.

2) If the two feet are functionally dissimilar, remove the results from the preliminary study and focus solely on the main study instead.

Major Comment 2:

The main focus of this study is to develop a foot that replicates human behavior on uneven terrain. However, there is no able-bodied reference data for walking on uneven surfaces. I believe that the authors should record able-bodied data for steps on uneven terrain to establish a reference point for assessing whether the prosthesis design is achieving its desired effect. The differences between the SoftFoot Pro and the Triton do not support the hypothesis of this study.

Minor Comments

Minor Comment 1:

Title: "Soft Robotic Prosthetic Foot"

This is a misleading description because there is nothing robotic about this foot.

Minor Comment 2:

Abstract: "Tests with two unilateral prosthetic users".

This should include that they are transtibial amputees.

Minor Comment 3:

Abstract: "The more evenly distributed load between limbs reduces compensatory strategies and gait asymmetries."

This statement must be supported by comparisons to able-bodied data.

Minor Comment 4:

Introduction: "lower the body's centre of mass, and during swing to increase foot ground clearance⁷; vaulting or hip hiking¹¹."

This sentence is confusing and seems to be improperly punctuated. Please revise.

Minor Comment 5:

Introduction: "The passive Triton Side Flex (Ottobock) features an ankle unit allowing 10° inversion/eversion (<https://www.ottobock.com/en-gb/product/1C68>)"

The authors should include reference to the MetaArc from Willowood which provides inversion/eversion and cite the relevant literature <https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=5951743>.

Minor Comment 6:

Introduction: "Over the past two decades..."

This statement should reference actual devices instead of just review papers. To name a few, you should reference:

<https://www.science.org/doi/10.1126/scirobotics.abo3996>

<https://www.sciencedirect.com/science/article/pii/S0893608008000683>

<https://ieeexplore.ieee.org/abstract/document/9636324>

Minor Comment 7:

Introduction: "and on the interface..."

This should reference relevant experiments in addition to the review paper, such as:

<https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=5951743>

Minor Comment 8:

Introduction: "...rotational axes at the midfoot or metatarsophalangeal joints^{18,28}"

Other relevant literature to cite here includes:

<https://www.science.org/doi/10.1126/scirobotics.abo3996>

Minor Comment 9:

Introduction: "A flexible toe joint was, for instance, preferred to a rigid one by LLPUs for navigating uneven terrains."

This statement requires a citation to support it.

Minor Comment 10:

Introduction: "The project stems from a soft foot for robotic applications³⁷, ..."

The difference between the previous design and this design must be discussed somewhere in the text. The difference between the previous work done studying the original design must also be specified.

Furthermore, why does this sentence reference robotic applications when this work is in a non-robotic application?

Minor Comment 11:

Introduction: "We hypothesised that this design could facilitate obstacle negotiation for LLPUs, by mainly reducing gait modifications on uneven terrains and thereby improving gait symmetry."

"Hypothesized" is misspelled. Secondly, this statement cannot be made without showing that the performance of the SoftFoot Pro produces behavior closer to able-bodied references.

Minor Comment 12:

Results: "...allows plantarflexion and dorsiflexion"

Please provide total possible range of motion of the device.

Minor Comment 13:

Results: "A follow up, shorter design with simplification of the small sole bodies."

Why was the design changed? What were the functional differences? These changes must be discussed.

Minor Comment 14:

Results: "...and then a rectangular shaped obstacle"

Please specify which size rectangle this is.

Minor Comment 12:

"Mean values across 5 strides (3 for level walking..."

This is a distinctly low number of strides for providing meaningful data. Why did you use so few trials? If possible, you should collect more data.

Minor Comment 15:

Results – Fig. 4: "Grey-shaded areas correspond to reference data from individuals without impairment for level walking (± 1 SD)."

Please cite the able-bodied reference data used each time you mention using it.

Minor Comment 16:

Results – Fig. 4/6/7

Why does only the ankle torque data show standard deviation shading?

Minor Comment 17:

Results / Supplementary Table 7: "knee flexion for the prosthetic side until push-off" / "Knee mean sagittal angle (deg) until the onset of pre-swing"

Please revise one of these statements to use consistent language describing the period of the gait cycle.

Minor Comment 18:

Results: All figures

Please move the location of the figures so that they are closer to the text describing them.

Minor Comment 19:

Results – Fig. 5: "vGRF" y axis label, "GRFv" caption label.

Please make these notations consistent.

Minor Comment 20:

Extended Data Fig. 5

It looks from this figure like you have 5 able-bodied people who stepped on the uneven terrain for these photos. Why did you not record data of them walking over the uneven terrain to compare able-bodied performance to the prostheses?

Minor Comment 21:

Discussion: "...filtering disturbances and enhancing stability."

This statement is not logically supported by the experiments or the discussion. Symmetry, differences in torque, angle, etc. are not equivalent to enhancing stability.

Minor Comment 22:

Discussion: "Testing with prosthetic users highlighted the SoftFoot Pro's superior performance on uneven terrains compared to passive carbon fibre prosthetic feet..."

"Superior" performance is not supported by this study because there is no way to determine what optimal performance is.

Minor Comment 23:

Discussion: "Plantar pressure mapping revealed its human-like ground adaptation..."

This statement is not supportable because plantar pressure mapping for the conventional passive prosthesis is not shown, and being "human-like" is subjective.

Minor Comment 24:

Discussion: "...a more controlled forward body progression."

What does this mean? This is not logically supported by this study.

Minor Comment 25:

Discussion: "Results of the preliminary study demonstrated the advantages of the anthropomorphic prosthetic design, particularly the greater prosthetic ankle joint ROM. The main study confirmed these benefits and highlighted those for the contralateral sound limb."

Going back to my previous comment, it is not clear why there are effectively two studies presented in one paper.

Minor Comment 26:

Discussion: "Reduced contralateral limb loading with the SoftFoot led to smaller increases in the same-side stance knee

flexion angle, torque (increase..."

This statement is not logically supported, and requires more discussion.

Minor Comment 27:

Discussion: "Thus, the SoftFoot mitigated excessive compensations in the contralateral sound limb."

This statement is not supportable without able-bodied references to define what "excessive" compensations are.

Minor Comment 28:

Discussion: "They were able to step on obstacles naturally without having to carefully approach them with the prosthetic hindfoot or midfoot, as..."

This statement is contradicted by the fact that users walked slower with the SoftFoot. It also appears evident in the videos that the users approached the uneven terrain slower and more cautiously. I think this statement is a stretch.

Minor Comment 29:

Fig 8: "through modified walking boots"

How were the boots modified?

Minor Comment 30:

Discussion: "Future design improvements will primarily focus on enhancing push-off ankle power generation."

Describing pushoff ankle behavior as "power generation" is misleading because a passive prosthesis does not generate power. It can only store and return energy.

Minor Comment 31:

Discussion: "In conclusion, this study proposed and validated the application of soft robotics principles..."

Soft robotics is not discussed or applied in this study, how does the study validate this application?

Minor Comment 32:

Discussion: "...potentially reducing the risk of osteoarthritis in the contralateral limb and benefiting users' long-term health."

Requires a citation that shows that more symmetrical loading reduces the risk of OA.

Minor Comment 33:

Supplementary Table 12 – Statement S1 has no response for the SoftFoot Pro.

Version 1:

Reviewer comments:

Reviewer #1

(Remarks to the Author)

The manuscript has been revised as suggested. The manuscript can be accepted for publication.

Reviewer #2

(Remarks to the Author)

Dear authors, Thank you for addressing the comments in my first review. In my opinion, these changes improved both the readability and the paper's overall impact. I have no additional major comments. However, I would like to ask the reviewers to address the following minor comments:

Minor comment 1: Figure formatting

Several figure captions, including Fig. 4 and 7 are slightly cut off by the page margin.

Minor comment 2: Supplementary Fig. 1

Missing legend.

Minor comment 3: Figure Text Sizes

On all figures it would be helpful for the authors to increase the text size that it is easier to read.

Minor comment 4: Missing Indents

Line 233 and Line 380.

Minor comment 5: Anatomy clarification.

I may be incorrect in assuming the author's intended design, but I believe the word "aponeurosis" in line 391 should instead refer to the full plantar "fascia".

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Reviewer #1

The manuscript titled “The SoftFoot Pro: an Anthropomorphic and Adaptive Soft Robotic Prosthetic Foot” presents a novel approach to prosthetic foot design, particularly in its anthropomorphic and adaptive characteristics. However, the following comments and queries are raised for consideration:

Thank you very much for all the comments and queries. They have led us to take several actions to improve the quality of the work. Please refer to the following answers and the revised version of the manuscript for more details.

C1.1-R1) *Theoretical formulations are essential for understanding the various mechanical behaviours of the prosthetic foot. The current manuscript presents only experimental results.*

A1.1-R1) We acknowledge that theoretical formulations are indeed essential for understanding the mechanical behaviour of the prosthetic device. We have now added a *Mathematical Model* sub-subsection to the *Prosthetic foot design* subsection of the *Methods*, presenting a more comprehensive rationale for the adaptive sole design and the governing set of equations linking foot configuration q , design parameters, and external loading conditions. We have then provided complete derivation of the key mathematical relationship presented in the main text in the supplementary materials only to reduce the manuscript length (see **Supplementary Note 3 | Mathematical Model**). The *Methods* section has been revised as follows:

*“Technically, the advantage of having an adaptive sole is to achieve a uniform pressure distribution on the largest possible contact area when the foot is in contact with small asperities, without requiring large ankle compensations. On flat terrain, a traditional artificial foot with a rigid flat sole enables a uniform pressure distribution across the base of support. The support length (i.e. the projection of the base of support in the sagittal plane, see S in **Supplementary Fig. 13**), within which the vertical projection of the center of mass (COM) must lie for stability, is given by the entire foot length (L in **Supplementary Fig. 13a**). However, this support length reduces when negotiating obstacles. In such conditions, indeed, maintaining balance requires either positioning the COM projection within the substantially reduced support length (corresponding to the obstacle area) (**Supplementary Fig. 13b**), or an active compensation at the ankle joint (see a in **Supplementary Fig. 13c**) to counteract the foot rotation induced by the obstacle, mitigating the reduction of the support length. A possible solution to address the limitations of flat feet on ground irregularities involves artificial feet with compliant flat soles, obtained for instance by adding layers of visco-elastic materials, silicon, or rubber at the bottom of the foot sole⁷². The compliant sole allows absorption of the small obstacles, enhancing ground adaptation, and avoiding ankle compensations and the reduction of the support length (**Supplementary Fig. 13e**). However, even a homogeneously compliant sole introduces tilting, which necessitates compensation. Moreover, such tilting phenomenon persists also on flat terrains, jeopardising stability (**Supplementary Fig. 13d**). An alternative solution to both rigid and homogeneously compliant flat feet is given by the adoption of an adaptive sole like the one embodied in the SoftFoot Pro. On flat terrain, it ensures the same performance of a traditional flat foot, with a support length corresponding to the entire foot whilst eliminating tilting issues (**Supplementary Fig. 13f**). On ground asperities, the foot sole conforms, distributing contact forces along an extended support length that more closely approximates that achieved on a flat terrain (**Supplementary Fig. 13g**). In addition, the sole stiffens under load once the contact with the ground has occurred. Consequently, stability improves and ankle compensation is not required. To achieve such conformability while maintaining sufficient support of all foot parts in contact, a detailed design of the SoftFoot components has to be developed based on accurate but manageable mathematical modelling.*

*To do so we adopt the general framework presented in Piazza et al. (2024)⁴⁸ and apply it to the specific prosthetic-oriented design of the SoftFoot Pro, including eight sole bodies of various lengths and the heel component. The complete model is presented in the **Supplementary Note 3 (Mathematical Model)**. By imposing the force and torque equilibria on the foot as a whole and on each of its components, by considering the elastic effects and tendon coupling in the sole as well as the constraints imposed by the ground and tendon, and by applying the small angles hypothesis, we obtain a set of $n + 6$ equations in $n + 6$ unknowns (q , T , F)*

$$\begin{aligned} & \begin{bmatrix} \ddot{q} \\ -B \end{bmatrix} [P^T d] \\ & \begin{bmatrix} \ddot{q} \\ \ddot{q} \end{bmatrix} \begin{bmatrix} g_{AT} \ddot{q} + m \ddot{q} \end{bmatrix} \end{aligned} \quad (1)$$

where $q = [q_1 \dots q_{n+2}] \in \mathbb{R}^{n+2}$ represents the prosthetic foot configuration ($n = 6$, being n the number of sole bodies included between the heel and the metatarsophalangeal joint); $T \in \mathbb{I}$ the tendon tension; $F \in \mathbb{R}^3$ the vector of contact forces between the foot and the ground; $P \in \mathbb{R}^{I \times n+2}$ collects the pulley radii r_i ; δ and $\sigma \in \mathbb{I}$ represent the constraints imposed by ground contact and by the tendon, respectively; $B \in \mathbb{R}^{n+2 \times n+2}$ collects the elastic terms and also depends on the sole bodies' size, on the design of the frontal and rear arches, and on the body weight acting on the foot; $d \in \mathbb{R}^{n+2 \times 3}$ and $C \in \mathbb{R}^{I \times n+2}$ depend on the length of the foot sole bodies; and $m \in \mathbb{R}^{n+2}$ depends on the sole bodies' size, on the design of the frontal and rear arches, on the body weight acting on the foot, and on the stiffness of the heel springs.

Through this equation, an optimization procedure to select the design parameters can be used that maximizes the contact area over a set of shapes and forces encountered in standard walking conditions, as originally envisioned in our initial conceptualization of adaptive feet compared to rigid and fully compliant designs (**Supplementary Fig. 13**). A list of design parameters selected for the SoftFoot Pro described in this paper is presented at the end of **Supplementary Note 3 (Mathematical Model)**.

C1.2-R1) **Additionally, the measurement procedures are not described in the Methods section, which would aid reader comprehension and reproducibility.**

A1.2-R1) We have now included the measurement procedures in the Methods section, by revising the second subsection of the *Results* and the *Methods* as follows:

Results - Validation of the SoftFoot Pro with prosthetic users. “The SoftFoot Pro was tested with a prosthetic user with knee rotationplasty in collaboration with the Laboratory for Biomechanics and Bio-materials, Hannover Medical School (henceforth Case Study I (CSI)), and with an individual with unilateral transtibial amputation and osseointegration, in collaboration with the Clinical Laboratory for Bionic Extremity Reconstruction, Medical University of Vienna, and Imperial College London (Case Study II (CSII), **Supplementary Table 1**). Results from level ground walking and obstacle stepping are presented below for the two case studies, with reference data from unimpaired individuals.”

Methods - Data collection and processing. “The SoftFoot Pro was tested with two individuals with different amputations (demographics in **Supplementary Table 1**). They both gave their informed consent to the testing protocol, which was approved by the local Ethics Committee of the Hannover Medical School and the Bioethical Committee of the University of Pisa. The two prosthetic users were fitted to the prototype by a certified prosthetist, and a 30-minute familiarization session preceded data collection in both case studies to allow the participants to gain some experience with the adaptive foot.

Participants were asked to walk at a self-selected speed on level ground, and then to repeat the task while stepping on an obstacle placed on a force plate. An arched-shaped (maximum height of 50 mm) and a rectangular-shaped (100 mm × 30 mm) obstacles were used (see **Extended Data Fig. 5** and further details in ⁵³), which were previously used in the bench testing of the SoftFoot⁴⁸. Each task was performed 6 times in CSI and 5 times in CSII. Testing was conducted first using the participant's own carbon fibre foot (Triton by Ottobock), then with the SoftFoot Pro. Comments by both studies' participants about the prostheses' performance were gathered.

In Case Study I, which consisted of a one-day assessment, tasks were performed donning the same pair of trekking shoes (model Quechua NH100) with both prostheses. Kinematic data were collected at 200Hz through a 12-camera motion capture system (type MX, Vicon Motion Systems Ltd., Oxford, UK). Sixteen reflective passive markers were placed on the participant's body according to the Helen Hayes marker set⁷². GRFs were captured at 1kHz through two force plates (AMTI BP400600, Watertown, USA). Data were processed offline in Vicon Nexus, and filtered using a low-pass filter with a cut-off frequency of 12 Hz.

In Case Study II - a two-day assessment - the participant wore [...].”

C2-R1) **The theoretical modelling of the sole's mechanism is not provided. It is unclear how the individual links were designed specifically for this prosthetic foot.**

A2-R1) We acknowledge the reviewer's concern. As explained in answer (A1.1-R1), we have now added a *Mathematical Model* sub-subsection in the *Methods* presenting the theoretical framework underlying the sole design and behaviour, which is then detailed in **Supplementary Note 3 — Mathematical Model**.

Furthermore, we have now moved the last paragraph of the subsection Prosthetic foot design of the Methods to the beginning of the subsection, and incorporated additional details about the design of the sole bodies, which were absent from the previous manuscript draft. The corresponding section has been revised as follows:

Methods - Prosthetic foot design. “The size and mass of the SoftFoot Pro match those of the missing anatomy. Anthropometric data from the 70th percentile⁶⁹ were considered for the design process, indicating height and weight of about 178 cm (the average male height in most European countries is between 175 cm and 180 cm⁷⁰) and 80 kg, with a foot length of 26.9 cm and a width of 9.9 cm. The height and mass of the SoftFoot prototype are approximately 11 cm from the ground to the base of the male adapter and 0.70 kg. The latter is close to the mass of common carbon fibre feet (e.g. around 0.65 kg for the Vari-Flex by O’ssur with aesthetic cover, size 27), and it is smaller than the mass of the human foot and shank segments at the same height as the SoftFoot (approximately 1.35 kg⁷¹). The prosthetic foot measures about 26 cm in length and 7.5 cm in width.

Anthropometric proportions in the sagittal plane typically position the ankle joint axis at a horizontal distance from the posterior extremity of the calcaneus of approximately 25% of the foot length, whilst the metatarsophalangeal joint is located at approximately 50% of the foot length from the ankle axis⁶⁹. The ankle joint and metatarsophalangeal joint axes of the SoftFoot Pro were designed accordingly. Similarly, in the vertical direction, the prosthetic ankle joint axis distance from the ground follows that of the intact counterpart of approximately 5% of the person’s height. As previously mentioned, the frontal and rear arches are connected through a revolute joint with a ball bearing, acting as the ankle joint. The rotational DoF in the sagittal plane around this transverse axis is only limited by the motion of the frontal arch being flush with respect to the rear arch. The rear arch is linked to the heel via a revolute joint given by a steel pin.

The foot sole comprises five parallel modules, each consisting of eight small 3D-printed rigid bodies (*Fig. 2*). They were sized to be as compact as possible whilst accommodating the internal components (i.e., plastic plain bearing bushing - GSM-0608-05 by IGUS, the wire, and the elastic bands) and ensuring proper functionality. The sole, particularly the longitudinal distance between the calcaneus and the metatarsophalangeal joint in the unloaded foot configuration, was constructed using the maximum whole number of those small bodies, with the remaining space filled through appropriate sizing of the first small body.”

It should be noted that the entire manuscript has also been revised following the second reviewer’s suggestions and comments. The main changes include presenting a single design of the SoftFoot Pro, given that the two adaptive prosthetic feet tested in the preliminary and main studies are identical, thereby avoiding potential reader confusion. However, given the differences in amputation types between participants and the consequent different biomechanics, we maintain separate result presentations as two distinct case studies, both of which are presented in the main text (see response (A1-R2) to Major Comment 1 of Reviewer 2 for more details). Also, for clarity, we show only results from the largest obstacles, which were tested in both case studies and produced the most significant gait perturbations (refer to the same response (A1-R2) to Reviewer 2’s Major Comment 1).

C3-R1) *No design calculations are included, particularly regarding the selection of spring stiffness, which is crucial for performance.*

A3-R1) We acknowledge that design calculations for spring stiffness selection were not included. We have now incorporated detailed information about the spring stiffness determination methodology in the supplementary material (see Supplementary Note 2 |Heel Springs Sizing). We have also revised the Methods section accordingly as follows:

Methods - Prosthetic foot design. “Two coil springs (music wire, spring constant approximately 40 N/mm, T.100.200.0296.A by Vanel) connect the rearmost small rigid body to the rear arch through steel pins (*Fig. 2, Extended Data Fig. 1*). The stiffness of the two springs was determined to prevent foot sole slapping at heel contact, thereby ensuring a smoother loading response phase, whilst withstanding the load acting on the heel at the beginning of the gait cycle. Specifically, the springs were sized considering a 2065 N load acting at the heel, as defined by the ISO 10328 standard for static proof testing of ankle-foot devices at a P4 loading level (body mass up to 80 kg). Based on the geometry of the links, the force transmitted to the springs was calculated using static equilibrium principles, and subsequently their required stiffness was determined (refer to *Supplementary Note 2* for further details).”

C4-R1) *If the sole is described as flexible, how can it simultaneously be inextensible? This apparent contradiction needs to be clarified.*

A4-R1) By flexible but inextensible material or object we usually mean one that can bend, fold, or deform its shape easily without requiring much force, but cannot stretch or elongate appreciably under tension. Examples of such materials are paper sheets, strings, taut cables, and tendons. The sole can be simultaneously flexible and inextensible due to the mechanical properties of the Liros pre-stretched coated Dyneema 266 SK 75 wire (DC000-0200) that connects all small bodies within each sole module, from heel to toe. Dyneema SK 75 cables are, indeed, characterised by high strength, low density, and low elongation at break¹. Despite their high modulus, the fibres the cable is made of are flexible with a long flexural fatigue life. According to the manufacturer's datasheet², this cable exhibits 3-4% elongation at breakload with a minimum break load of 2000 N, significantly exceeding the maximum loads acting on each sole module. Furthermore, the pre-stretching process substantially reduces the "bedding-in" elongation, which is the permanent elongation occurring at first use caused by the fibres settling into the most efficient load path³.

Therefore, the cable's negligible flexural rigidity enables adaptation to imposed loading configurations without resistance to bending moments, hence providing flexibility. Simultaneously, under tensile loads during gait (e.g. see the peaks in antero-posterior component of ground reaction forces (GRF)), the cable elongation remains negligible. For example, considering a 100 kg subject, an antero-posterior GRF peak of approximately 30% body weight (see reference data in Fig. 5), and the distribution of this force (295 N) among the five parallel sole modules, each cable experiences significantly less than 295 N, resulting in a minimal elongation (the elongation at 300 N is between 0.40 and 0.78% according to the datasheet⁴). Given these negligible changes in length, the inextensible behaviour represents a valid simplifying assumption. We have clarified this concept in the manuscript as follows:

Results - Overview of the SoftFoot Pro.

"The sole comprises five parallel modules, each consisting of small bodies connected through elastic bands and a wire that exhibits inextensible behaviour under load (detailed design description in the Methods section). This configuration provides compliant interaction with the environment, enlarging the ground contact area and enabling effective obstacle negotiation whilst supporting the user's body weight (BW). The sole's behaviour is passively determined by environmental interaction through the combined action of elastic bands and wire responding to the ground profile and the user's load. As it bends to match the ground profile, the sole exhibits non-linear stress-stiffening behaviour under load⁴⁸ (with stiffness increasing primarily due to the wire characteristics), before returning to its original shape when unloaded (via elastic band action). This behaviour arises from the wire's properties: negligible flexural rigidity for easy deformation, thus conformity to ground profiles, as well as negligible elongation under load."

C5-R1) *How was the stability of the prosthetic foot evaluated? Information on assessment methods is lacking.*

A5-R1) We thank the reviewer for this important observation regarding stability assessment. We acknowledge that the current study did not include quantitative stability evaluation, which represents a limitation that we have now explicitly stated.

In this work, we focused primarily on demonstrating the SoftFoot Pro's adaptive capabilities and biomechanical performance during gait on various surfaces. While our results show successful adaptation to different terrains and obstacle negotiation, we did not assess dynamic stability through established metrics such as the medio-lateral margin of stability, the medio-lateral motion of the centre of mass, step width, step width variability, or the velocity of the lateral arm-swing^{4,5}; or also the stride time, the double support time, and the maximum lateral excursion of the centre of pressure trajectory⁶.

¹<https://pelicanrope.com/content/PDFs/Dyneema-Comprehensive-factsheet-UHMWPE.pdf>

²[https://www.liros.com/userdata/files/LIROS flightsport brochure 2024 DINa5 hoch 28s low res.pdf](https://www.liros.com/userdata/files/LIROS%20flightsport%20brochure%202024%20DINa5%20hoch%2028s_low%20res.pdf)

³<https://www.marlowropes.com/innovation/dyneema-rope/dyneema-tech-info/>

⁴Gates, D. H., Dingwell, J. B., Scott, S. J., Sinitski, E. H., & Wilken, J. M. (2012). Gait characteristics of individuals with transtibial amputations walking on a destabilising rock surface. *Gait & Posture*, 36(1), 33-39. <https://doi.org/10.1016/j.gaitpost.2011.12.019>

⁵Curtze, C., Hof, A. L., Postema, K., & Otten, B. (2011). Over rough and smooth: Amputee gait on an irregular surface. *Gait & Posture*, 33(2), 292-296. <https://doi.org/10.1016/j.gaitpost.2010.11.023>

⁶Kendell, C., Lemaire, E. D., Dudek, N. L., & Kofman, J. (2010). Indicators of dynamic stability in transtibial prosthesis users. *Gait & Posture*, 31(3), 375-379. <https://doi.org/10.1016/j.gaitpost.2010.01.003>

The observations on stability reported in our study were based on qualitative assessment during experimental trials, specifically by observing the absence of balance perturbations. However, we recognise that this does not constitute a rigorous dynamic stability evaluation. Hence, we have revised the manuscript to clarify this limitation:

“Furthermore, a comprehensive assessment of dynamic stability remains to be conducted. Future studies will employ established metrics^{60–62} to quantitatively assess it during locomotion on various surfaces, comparing the SoftFoot Pro with conventional non-adaptive prostheses and unimpaired subjects.”

with

60. Kendell, C., Lemaire, E. D., Dudek, N. L. & Kofman, J. Indicators of dynamic stability in transtibial prosthesis users. *Gait & Posture* 31, 375-379 (2010). <https://doi.org/https://doi.org/10.1016/j.gaitpost.2010.01.003>
61. Curtze, C., Hof, A. L., Postema, K. & Otten, B. Over rough and smooth: Amputee gait on an irregular surface. *Gait & Posture* 33, 292-296 (2011). <https://doi.org/https://doi.org/10.1016/j.gaitpost.2010.11.023>
62. Gates, D. H., Scott, S. J., Wilken, J. M. & Dingwell, J. B. Frontal plane dynamic margins of stability in individuals with and without transtibial amputation walking on a loose rock surface. *Gait & Posture* 38, 570-575 (2013). <https://doi.org/https://doi.org/10.1016/j.gaitpost.2013.01.024>

C6-R1) ***What is the functional role of links 7 and 8? They appear to serve primarily aesthetic purposes, and their contribution to the overall mechanism should be clarified.***

A6-R1) Links 7 and 8 represent the toe phalanges and serve crucial functional roles rather than merely aesthetic purposes. Their biomechanical contributions to the prosthetic mechanism are twofold:

- *First, enhanced base of support:* Links 7 and 8 are passively underactuated when the foot is loaded due to the specific routing of the aforementioned cable within the small bodies of each sole module. This mechanism enables the toes to exert a pushing force against the ground, thereby enlarging the base of support for the prosthesis user. This behaviour is amplified when an obstacle is encountered in the sole region between the heel component and the metatarsophalangeal joint: the cable further strains, passively increasing toe plantarflexion. This response enhances the foot’s grip on the ground’s surfaces, mimicking the adaptive behaviour of a sound human foot.
- *Second, push-off support:* During the push-off phase, when the forefoot is the primary load-bearing area, links 7 and 8 remain part of the support base, contributing to balance.

Plantar pressure measurements during walking (Fig. 8) demonstrate the loading on links 7 and 8, particularly in the external sole modules, during both level and obstacle walking. Furthermore, the centre of pressure trajectory extends beyond the metatarsophalangeal joint region, confirming that the GRF acts beneath the toe phalanges. We have enhanced the manuscript with additional details about toe functionality in the *Prosthetic foot design* subsection of the *Methods* section:

*“In addition, as a result of the peculiar design of the 5th and 6th bodies and the routing of the inextensible wire within them, the toes are passively underactuated and assume a curved configuration when loaded. The distal phalanges exert a pushing force on the ground, enlarging the base of support for the prosthesis user. When obstacles are encountered between the heel and metatarsophalangeal joint, the wire further strains, passively increasing toe plantarflexion and enhancing the foot’s grip on the ground, similar to the human foot (**Extended Data Fig. 3**). During push-off, when the forefoot is the primary load-bearing region, the toes maintain their supportive role, as evidenced by the high plantar pressures recorded on these segments, particularly in the external modules (**Fig. 8**).”*

Reviewer #2

This paper presents the new design of a unique prosthetic foot/ankle called the SoftFoot Pro. The device's distinctive design features a flexible, inextensible artificial tendon that mimics the plantar fascia of the foot and toe. This allows the foot to adapt to uneven terrain, similar to a human foot. By achieving biomimetic adaptation to diverse surfaces, the authors hope that the foot will facilitate biomimetic movement in the contralateral limb and other body parts. I believe that the core concept motivating this design is sound and could enhance ambulation for users. However, I have significant concerns about how the information is presented and compared here, as well as the conclusions that the authors draw from the experimental data.

We thank the reviewer for understanding the core concept behind the design of the SoftFoot Pro and also for raising concerns about the way information is presented and compared, and conclusions are drawn. This has allowed us to improve the quality of the manuscript, clarifying important aspects of our work by addressing the comments made. Please see below for answers to your comments. The revised text of the manuscript is also reported for each answer where necessary, with changes highlighted in red.

Major Comments

MC1-R2) *Major Comment 1: It is not clearly explained why there are two different designs presented in this paper: the Main Study and the Preliminary Study. The differences between the two foot designs are briefly discussed and illustrated in a figure, but the authors do not address the functional differences between the feet or the reason for the redesign. Moreover, it is confusing and challenging for the reader to go through the results of the preliminary study in the supplementary material and then compare them to the results of the main study in the main text. I would offer two suggestions: 1) If the two feet are functionally similar in performance, combine the results of both participants into one set of results and discuss why the feet are functionally similar. 2) If the two feet are functionally dissimilar, remove the results from the preliminary study and focus solely on the main study instead.*

A1-R2) There are no functional differences between the two foot designs: they embody the same components and operate according to identical working principles. There are only two minor differences that do not affect functionality: (1) the distance between the ankle joint and the proximal end of the prosthetic foot, which was greater in the first design to directly match the height of the original prosthesis used by the participant of the preliminary study; (2) the length of the small sole bodies, which differs between the two designs to match the different foot sizes of the two participants whilst keeping the same number of bodies in the sole. Given that both prosthetic feet are functionally identical, we have amended the entire manuscript to present a single design, eliminating potential confusion.

Regarding the reviewer's suggestion to combine results if the feet are functionally similar: whilst the devices are functionally identical, we believe it may be better to present the results separately given the differences in amputation types between participants. The preliminary study involved a participant with knee rotation-plasty (where the knee joint is actually an ankle joint), whilst the main study involved a participant with transtibial amputation and osseointegration. These different amputation types result in distinct biomechanical characteristics that may warrant separate analysis.

We understand that it might be challenging for the reader to go through the results of the preliminary study in the supplementary material and then compare them to the results of the main study in the main text. To address this aspect, we have moved the results of the preliminary study from the supplementary material to the main text, presenting them alongside the results of the main study as *Case Study I* and *Case Study II*, respectively. This revision should facilitate comparison whilst maintaining the clinical relevance of each case.

Lastly, to further enhance clarity and focus on the most relevant results, we present in the main text only results from the largest obstacles (big rectangle and big arch), which were tested in both case studies and produced the most significant gait perturbations. Data from smaller obstacles, which provided limited additional insights, have been removed.

MC2-R2) *Major Comment 2: The main focus of this study is to develop a foot that replicates human behaviour on uneven terrain. However, there is no able-bodied reference data for walking on*

uneven surfaces. I believe that the authors should record able-bodied data for steps on uneven terrain to establish a reference point for assessing whether the prosthesis design is achieving its desired effect. The differences between the SoftFoot Pro and the Triton do not support the hypothesis of this study.

A2-R2) To address this gap and strengthen the current study, we have collected gait data from 12 unimpaired subjects performing the same walking tasks (flat ground and stepping on the same obstacles used in the present study). These reference data have now been incorporated into the revised manuscript. We have specified this information in the *Results - Validation of the SoftFoot Pro with prosthetic users* subsection:

“Reference data from 12 unimpaired individuals walking on level ground and stepping on obstacles (10 repetitions per task using the Oxford Foot Model marker set) are used for comparison in the sagittal plane. For the obstacle condition in CSII, contralateral sound limb data refer to the stride on flat ground following the prosthetic limb’s step on the obstacle, enabling direct comparison with level ground reference data.”

This addition enables a more comprehensive evaluation of the SoftFoot Pro’s performance relative to both conventional prosthetic feet and unimpaired subjects on uneven surfaces, as demonstrated by the revised comparisons in the Abstract, Results and Discussion sections.

Minor Comments

mC1-R2) **Minor Comment 1: Title: “Soft Robotic Prosthetic Foot”. This is a misleading description because there is nothing robotic about this foot.**

a1-R2) We thank the reviewer for this observation. We acknowledge that the term “robotic” is indeed misleading in this context, as the prosthetic foot operates through passive mechanisms. We have therefore removed the word “robotic” from the title, which now is “*The SoftFoot Pro: an Anthropomorphic and Adaptive Soft Articulated Prosthetic Foot*”, and throughout the manuscript when referring to the proposed prosthetic foot.

mC2-R2) **Minor Comment 2: Abstract: “Tests with two unilateral prosthetic users”. This should include that they are transtibial amputees.**

a2-R2) We have revised the abstract to include the specific level of amputation for clarity: “Tests with two unilateral *transtibial* prosthetic users [...]”

mC3-R2) **Minor Comment 3: Abstract: “The more evenly distributed load between limbs reduces compensatory strategies and gait asymmetries.”. This statement must be supported by comparisons to able-bodied data.**

a3-R2) We have added reference data from unimpaired subjects for stepping on obstacles for comparison purposes, ensuring that also this statement is appropriately supported. We have also modified the phrase in the abstract as follows: “*The more even load distribution between the two limbs reduces compensatory strategies and gait asymmetries, resulting in biomechanics closer to that of unimpaired individuals.*”

mC4-R2) **Minor Comment 4: Introduction: “lower the body’s centre of mass, and during swing to increase foot ground clearance⁷; vaulting or hip hiking¹¹.” This sentence is confusing and seems to be improperly punctuated. Please revise.**

a4-R2) The sentence has been revised for clarity and proper punctuation:

“Kinematic compensations comprise increased upper limb motion³, greater hip and knee flexion on the prosthetic side in transtibial users (both at stance onset to lower the body’s centre of mass and during swing to increase foot-ground clearance⁷), and compensatory movements such as vaulting or hip hiking¹¹.”

mC5-R2) **Minor Comment 5: Introduction: “The passive Triton Side Flex (Ottobock) features an ankle unit allowing 10° inversion/eversion (https://www.ottobock.com/en-gb/product/1C68_)” The authors should include reference to the MetaArc from Willowood which provides inversion/eversion and cite the relevant literature <https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=5951743>.**

- a5-R2) We thank the reviewer for this valuable suggestion, which has enabled us to provide a more comprehensive overview of the state of the art of prosthetic feet in the *Introduction*. We have revised the paragraph to include the suggested commercial prosthetic foot and have incorporated the suggested scientific reference:
- “While training can improve LLPUs’ balance in various environments, current commercial passive energy-storage-and-return prosthetic feet, mainly made of carbon fibre laminates, fail to ensure adaptability on uneven grounds (Fig. 1b). Surface adaptation is usually, indeed, tackled through split keels, which offer limited adaptation. Other passive solutions on the market include: the Evanto (Ottobock), which allows multi-planar motion through a pivot axis and foam wedges at the heel; the Triton Side Flex (Ottobock, <https://www.ottobock.com/en-gb/product/1C68>) and the META® Arc (WillowWood)¹⁵, both of which feature ankle units allowing 10° inversion/eversion. Commercial microprocessor-controlled prostheses like the Meridium and the Triton Smart Ankle (both by Ottobock), the Elan (Blatchford), and the Freedom Kinnex 2.0 (Proteor) can adapt to slopes and slightly enhance sagittal ankle joint range of motion (ROM) by actively modulating the ankle joint impedance. The Proprio Foot (Össur) improves swing ground clearance through an electric motor driving ankle rotation. The Meridium also includes a metatarsophalangeal joint axis for improved sagittal motion. Over the past two decades, research efforts have predominantly focused on developing active prosthetic ankles capable of generating biomimetic sagittal torque and power profiles across various tasks^{16–25}, advanced control algorithms for seamless locomotion mode transitions in powered leg prostheses^{16,26,27}, and bidirectional human-prosthesis interfaces enabling active device control^{26,28–30} and sensory feedback restoration^{29–31}.”*
- mC6-R2) *Minor Comment 6: Introduction: “Over the past two decades... ” This statement should reference actual devices instead of just review papers. To name a few, you should reference: <https://www.science.org/doi/10.1126/scirobotics.abo3996>, <https://www.sciencedirect.com/science/article/pii/S0893608008000683>, <https://ieeexplore.ieee.org/abstract/document/9636324>*
- a6-R2) We thank the reviewer for providing these specific references to actual devices, which strengthen our state of the art. We have added references to actual devices alongside existing review papers, including those suggested by the reviewer:
- “Over the past two decades, research efforts have predominantly focused on developing active prosthetic ankles capable of generating biomimetic sagittal torque and power profiles across various tasks^{16–25}, [...]”*
- mC7-R2) *Minor Comment 7: Introduction: “and on the interface... ” This should reference relevant experiments in addition to the review paper, such as: <https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=5951743>*
- a7-R2) We have revised the sentence to include references to relevant experimental studies in addition to the review paper, as follows:
- “Over the past two decades, research efforts have predominantly focused on developing active prosthetic ankles capable of generating biomimetic sagittal torque and power profiles across various tasks^{16–25}, advanced control algorithms for seamless locomotion mode transitions in powered leg prostheses^{16,26,27}, and bidirectional human-prosthesis interfaces enabling active device control^{26,28–30} and sensory feedback restoration^{29–31}.”*
- mC8-R2) *Minor Comment 8: Introduction: “. . . rotational axes at the midfoot or metatarsophalangeal joints^{18,28}” Other relevant literature to cite here includes: <https://www.science.org/doi/10.1126/scirobotics.abo3996>*
- a8-R2) We have incorporated the recommended reference along with additional related work to strengthen this section:
- “[...] while others attempt to emulate the flexibility of the human foot sole by embodying rotational axes at the midfoot or metatarsophalangeal joints (see for instance the powered toe joint of the Utah Bionic Leg²⁴ and other examples in 22.39).”*
- mC9-R2) *Minor Comment 9: Introduction: “A flexible toe joint was, for instance, preferred to a rigid one by LLPUs for navigating uneven terrains.” This statement requires a citation to support it.*

a9-R2) We have repositioned the corresponding reference from the following sentence to properly support this statement:
“A flexible toe joint was, for instance, preferred to a rigid one by LLPUs for navigating uneven terrains⁴⁰. It reduced the positive hip joint work in the prosthetic side.”

mC10-R2) *Minor Comment 10: Introduction: “The project stems from a soft foot for robotic applications³⁷, ... ” The difference between the previous design and this design must be discussed somewhere in the text. The difference between the previous work done studying the original design must also be specified. Furthermore, why does this sentence reference robotic applications when this work is in a non-robotic application?*

a10-R2) We thank the reviewer for this important question. The difference between the SoftFoot described in Piazza et al. (2024)⁷ and the SoftFoot Pro presented in this manuscript lies primarily in the fact that the latter has been specifically designed for prosthetic applications, respecting human anthropometry and incorporating standard prosthetic adapters for generalization to various amputation levels and prosthetic configurations.

About the previous work done studying the original design, the general theoretical framework describing the behaviour of an adaptive, articulated, soft foot⁷ underlay various practical implementations, such as (1) the SoftFoot for legged robotic systems^{7,8} and (2) the SoftFoot-Q for quadrupeds⁹. The former underwent extensive bench-testing demonstrating superior performance compared to rigid and compliant artificial feet in terms of equivalent support surface on obstacles and impact absorption⁷. It was also tested with the HRP-4 humanoid robot confirming improved obstacle negotiation capabilities compared to conventional flat feet, even without controller optimisation. The promising results from those implementations motivated the design and development of the prosthetic prototype presented in this manuscript - the SoftFoot Pro - based on the theoretical model detailed in the Supplementary Material (see **Supplementary Note 3**).

The introductory reference to robotic applications serves to contextualise the development of our prosthetic device. We have revised the corresponding section in the Introduction to clarify the distinction between the SoftFoot and the SoftFoot Pro, respectively for legged robots and prosthetic users:

“Here, we present the SoftFoot Pro: a prosthetic foot that passively provides ground adaptation across all terrains (**Fig. 1c, Fig. 2**). The project stems from an artificial adaptive foot, the SoftFoot⁴⁸, developed for legged robotic systems, which was designed according to a soft robotics approach⁴⁹ reminiscent of previous design approaches for artificial hands⁵⁰. It was developed to overcome the drawbacks of state-of-the-art robotic flat feet in unstructured environments. Bench-testing of the SoftFoot yielded promising results on obstacles in terms of support surface and absorption of impulsive forces, exceeding the performance of completely rigid and compliant artificial feet⁴⁸. The SoftFoot was also tested with the HRP-4 humanoid robot: it outperformed the robot’s original flat feet when negotiating obstacles, even without controller optimisation⁵¹. Therefore, building upon the promising performance of the SoftFoot in legged robotic applications, we developed its prosthetic counterpart, the SoftFoot Pro, which matches the human foot anthropometry and can be interfaced with any prosthetic leg through standard prosthetic adapters (suitable for amputation levels from transtibial to more proximal).”

mC11-R2) *Minor Comment 11: Introduction: “We hypothesised that this design could facilitate obstacle negotiation for LLPUs, by mainly reducing gait modifications on uneven terrains and thereby improving gait symmetry.” “Hypothesized” is misspelled. Secondly, this statement cannot be made without showing that the performance of the SoftFoot Pro produces behavior closer to able-bodied references.*

a11-R2) We have revised the verb. Concerning the comparison with able-bodied performance, we acknowledge the reviewer’s point and refer to our previous response (A2-R2) addressing this limitation. We have now incorpo-

⁷Piazza, C., Santina, C. D., Grioli, G., Bicchi, A., & Catalano, M. G. (2024). Analytical Model and Experimental Testing of the SoftFoot: An Adaptive Robot Foot for Walking Over Obstacles and Irregular Terrains. *IEEE Transactions on Robotics*, 40, 3290-3305. <https://doi.org/10.1109/TRO.2024.3415237>

⁸Catalano, M. G., Frizza, I., Morandi, C., Grioli, G., Ayusawa, K., Ito, T., & Venture, G. (2021). HRP-4 Walks on Soft Feet. *IEEE Robotics and Automation Letters*, 6(2), 470-477. <https://doi.org/10.1109/lra.2020.2979630>

⁹Catalano, M. G., Pollayil, M. J., Grioli, G., Valsecchi, G., Kolvenbach, H., Hutter, M., Bicchi, A., & Garabini, M. (2021). Adaptive Feet for Quadrupedal Walkers. *IEEE Transactions on Robotics*, 1-15. <https://doi.org/10.1109/TRO.2021.3088060>

rated able-bodied reference data throughout the *Results* and *Discussion* sections to enable comparison with the prostheses' performance.

mC12-R2) **Minor Comment 12: Results: “. . . allows plantarflexion and dorsiflexion” Please provide total possible range of motion of the device.**

a12-R2) We thank the reviewer for requesting this clarification. The range of motion at the ankle joint across different tasks is shown in Supplementary Table 2. In the unloaded configuration, the maximum relative rotation of the frontal arch with respect to the rear arch is approximately 24°, all in plantarflexion. We have added it to the text (see *Results - Overview of the SoftFoot Pro*):

“The rotation of the frontal arch relative to the rear arch, despite the latter being rigidly connected to the prosthetic shank, allows some plantarflexion and dorsiflexion (in the unloaded configuration, the maximum relative rotation of the frontal arch with respect to the rear arch is approximately 24°, all in plantarflexion).”

mC13-R2) **Minor Comment 13: Results: “A follow up, shorter design with simplification of the small sole bodies.” Why was the design changed? What were the functional differences? These changes must be discussed.**

a13-R2) We have addressed this point comprehensively in our response to the first major comment (A1-R2). As previously clarified, no functional differences exist between the design iterations, and these design modifications, i.e. “shorter design with simplification of the small sole bodies”, did not influence the device's performance or affect the study outcomes. In particular, whilst redesigning the dimensions of the small sole bodies to match different foot sizes (as explained in answer (A1-R2)), we made minor aesthetic modifications to the external appearance of these components. However, these represent minor superficial alterations that did not affect the prosthesis functionality in any way. Therefore, we have revised the manuscript to present a single design, avoiding potential confusion for readers, given that both designs are functionally identical.

mC14-R2) **Minor Comment 14: Results: “... and then a rectangular shaped obstacle” Please specify which size rectangle this is.**

a14-R2) We thank the reviewer for requesting this clarification. The dimensions of the obstacles used in the experimental activity are detailed in Extended Data Fig. 5. As explained in reply (A1) to major comment (MC1), we present now only results from the largest obstacles (big rectangle and big arch), which were tested in both case studies and produced the most significant gait perturbations, whilst results from smaller obstacles provided limited additional insights. We have modified the text in the *Data collection and processing* subsection of the *Methods* accordingly, to which this part about the experimental protocol has been moved, also adding the size of the obstacles:

*“An arched-shaped (maximum height of 50 mm) and a rectangular-shaped (100 mm × 30 mm) obstacles were used (see **Extended Data Fig. 5** and further details in⁵³), which were previously used in the bench testing of the SoftFoot⁴⁸.”*

mC15-R2) **Minor Comment 15: “Mean values across 5 strides (3 for level walking...) This is a distinctly low number of strides for providing meaningful data. Why did you use so few trials? If possible, you should collect more data.**

a15-R2) We collected five valid strides for each task, considering the specific challenges inherent in testing individuals with amputation, including increased fatigue resulting from biomechanical compensations. This approach aligns with established protocols in prosthetic research, where 3-8 strides are commonly considered to balance data quality with participants' fatigue. During the post-processing phase, we encountered technical issues with level walking data from the participant's own prosthetic foot, which prevented us from extracting five valid gait cycles for each limb (greater attention will be paid to this aspect in future studies). Consequently, we used three valid cycles, which remain consistent with what reported in the literature. A few gait studies are listed below as examples of the range of gait cycles commonly considered in the literature:

(a) Ferrari, A., Benedetti, M. G., Pavan, E., Frigo, C., Bettinelli, D., Rabuffetti, M., Crenna, P., & Leardini, A. (2008). Quantitative comparison of five current protocols in gait analysis. *Gait Posture*, 28(2), 207-216. <https://doi.org/10.1016/j.gaitpost.2007.11.009> in which “five to six walking trials were

recorded [...] and at least 3 gait cycles for each limb were selected on the basis of good quality of the marker trajectories and ground reaction forces.”

- (b) Fey, N. P., Klute, G. K., & Neptune, R. R. (2011). The influence of energy storage and return foot stiffness on walking mechanics and muscle activity in below-knee amputees. Clin Biomech (Bristol, Avon), 26(10), 1025-1032. <https://doi.org/10.1016/j.clinbiomech.2011.06.007> in which “Repeated trials were collected at each condition until at least five force plate contacts per leg were measured.”
- (c) Dumas, R., Brånemark, R., & Frossard, L. (2017). Gait Analysis of Transfemoral Amputees: Errors in Inverse Dynamics Are Substantial and Depend on Prosthetic Design. IEEE Transactions on Neural Systems and Rehabilitation Engineering, 25(6), 679-685. <https://doi.org/10.1109/TNSRE.2016.2601378> in which “Participants performed three successive trials of straight level walking at self-selected speed.”
- (d) Prost, V., Johnson, W. B., Kent, J. A., Major, M. J., & Winter, A. G. (2022). Biomechanical evaluation over level ground walking of user-specific prosthetic feet designed using the lower leg trajectory error framework. Scientific Reports, 12(1). <https://doi.org/10.1038/s41598-022-09114-y> in which “After at least five steps were collected on each side,[...].”
- (e) Bisele, M., Bencsik, M., Lewis, M. G. C., & Barnett, C. T. (2024). Attempted symmetry affects dynamic gait stability in individuals with lower-limb amputation. Gait & Posture, 107, 182-188. <https://doi.org/https://doi.org/10.1016/j.gaitpost.2023.09.015> in which “Five successful trials, defined as good contact between the participant’s foot and the force plate, were collected for both limbs in each condition” and also “For each trial, a minimum of three gait cycles were extracted for each limb.”

mC16-R2) **Minor Comment 16: Results – Fig. 4: “Grey-shaded areas correspond to reference data from individuals without impairment for level walking ($\pm 1SD$).” Please cite the able-bodied reference data used each time you mention using it.**

a16-R2) We have now included the citation whenever able-bodied reference data from the literature (i.e. for level walking in the frontal plane) are mentioned throughout the manuscript and supplementary material.

mC17-R2) **Minor Comment 17: Results – Fig. 4/6/7 Why does only the ankle torque data show standard deviation shading?**

a17-R2) We thank the reviewer for this question. To maintain visual clarity and avoid overloading the plots, we chose not to display standard deviations for both limbs and both prostheses across all variables. However, we specifically included standard deviation shading for the contralateral sound limb ankle torques to provide visual support for the inferential statistical analysis. The *t*-test was performed, indeed, to compare torques of the contralateral joints when evaluating differences in compensations between the two prostheses in case study II, making this particular visualisation most relevant for the statistical comparisons. We have included this information in the subsection *Data collection and processing* of the *Methods*, as follows:

*“Standard deviation shading for the contralateral sound limb ankle torques is displayed in CSII results to visually support the inferential statistical analysis in **Supplementary Note 1.**”*

mC18-R2) **Minor Comment 18: Results / Supplementary Table 7: “knee flexion for the prosthetic side until push-off” / “Knee mean sagittal angle (deg) until the onset of pre-swing” Please revise one of these statements to use consistent language describing the period of the gait cycle.**

a18-R2) We thank the reviewer for highlighting this inconsistency in terminology. To ensure consistent language throughout the manuscript, we have revised the text to always use “push-off” rather than “pre-swing” (see *Results* and Supplementary Table 8).

mC19-R2) **Minor Comment 19: Results: All figures Please move the location of the figures so that they are closer to the text describing them.**

a19-R2) We have repositioned all figures to be closer to the text describing them, ensuring better flow and easier cross-referencing for the readers.

mC20-R2) *Minor Comment 20: Results – Fig. 5: “vGRF” y axis label, “GRFv” caption label. Please make these notations consistent.*

a20-R2) We have amended the captions of Fig. 5, Supplementary Figures 1 and 3 to ensure consistent notation throughout.

mC21-R2) *Minor Comment 21: Extended Data Fig. 5 It looks from this figure like you have 5 able-bodied people who stepped on the uneven terrain for these photos. Why did you not record data of them walking over the uneven terrain to compare able-bodied performance to the prostheses?*

a21-R2) The photos shown in Extended Data Fig. 3 (previously Extended Data Fig. 5) were taken specifically to show the deformation of the SoftFoot’s sole when in contact with an obstacle, illustrating how it replicates, to some extent, the adaptive behaviour of the human foot sole. These images were captured for illustrative purposes to showcase the device’s passive adaptation mechanism rather than as part of a gait analysis study. However, as explained earlier in answer (A2-R2), a comprehensive comparison with able-bodied gait stepping on obstacles has now been added.

mC22-R2) *Minor Comment 22: Discussion: “. . . filtering disturbances and enhancing stability.” This statement is not logically supported by the experiments or the discussion. Symmetry, differences in torque, angle, etc. are not equivalent to enhancing stability.*

a22-R2) We thank the reviewer for this valid point. We acknowledge that our experimental measurements do not directly demonstrate enhanced stability. As also explained in our response to Reviewer 1 (A5-R1), our study currently lacks a quantitative evaluation of the prosthetic user’s dynamic stability, which will be addressed in future work. We have therefore revised the text, removing references to “enhancing stability” to ensure our conclusions are appropriately supported by the presented experimental results.

mC23-R2) *Minor Comment 23: Discussion: “Testing with prosthetic users highlighted the SoftFoot Pro’s superior performance on uneven terrains compared to passive carbon fibre prosthetic feet...” “Superior” performance is not supported by this study because there is no way to determine what optimal performance is.*

a23-R2) We recognise that the term “superior” implies a judgment against an optimal performance, which our study did not establish. We have now added data from unimpaired subjects walking on obstacles to be used as a reference for better assessing the performance of our adaptive foot and comparing it to that of the carbon fiber foot. The phrase mentioned by the reviewer, in particular, has been revised as follows:

“Testing with prosthetic users highlighted that the SoftFoot Pro performed better on uneven terrains than passive carbon fibre prosthetic feet, achieving overall a biomechanics closer to that of unimpaired individuals. Notably, prosthetic ankle ROM approached unimpaired values more closely than the carbon foot, and contralateral knee and hip torques on obstacles were substantially reduced with the SoftFoot and closer to unimpaired patterns. These findings support the initial hypothesis that the adaptive prosthesis mitigates gait modifications in LLPUs, improving gait symmetry.”

mC24-R2) *Minor Comment 24: Discussion: “Plantar pressure mapping revealed its human-like ground adaptation,... ” This statement is not supportable because plantar pressure mapping for the conventional passive prosthesis is not shown, and being “human-like” is subjective.*

a24-R2) We agree that our original statement was not adequately supported since we had not presented plantar pressure mapping data for the conventional passive prosthesis for direct comparison, and the term “humanlike” lacked objective quantitative criteria.

To address this limitation, we have collected plantar pressure mapping for the carbon fibre foot and added these comparative results in the text (see last paragraph of the *Results*) and in Fig. 9. We have also calculated the root mean square error value between the mean pressure maps of each prosthetic foot and that of the human foot on both flat ground and the obstacle to get a quantitative description of the differences in pressure distribution for each prosthesis compared to the human foot. We have revised the text of the *Results*, *Discussion*, and *Methods* sections accordingly:

Results - Validation of the SoftFoot Pro with prosthetic users. *“Lastly, when mounted under walking boots on an unimpaired individual⁵³ (see **Extended Data Fig. 2**), the adaptive foot showed negligible pressure at the midfoot during level walking due to its soft sole, with pressure peaks under the heel, metatarsal heads, and toes (**Fig. 8b,e**) resembling those of a sound foot (**Fig. 8a,d**). In contrast, the carbon foot’s aesthetic cover enabled continuous ground contact throughout stance (**Fig. 8c,f**). On an obstacle, this trend reversed. The SoftFoot adapted to the ground profile, maintaining broad contact from heel to forefoot (**Fig. 8h,m**), showing closer alignment with the human pressure distribution (**Fig. 8g,l**), whilst the carbon foot contacted only at the midfoot (**Fig. 8i,n**), as confirmed also by the shorter centre of pressure trajectory. Pressure peaks occurred at the obstacle’s edges. RMSE values quantified this inversion: on flat ground, the carbon foot showed lower deviation (0.29) than the SoftFoot (0.59), but on obstacles the SoftFoot improved (0.47 vs human-on-obstacle) whilst the carbon foot’s deviation increased (0.50 vs human-on-obstacle) (**Supplementary Table 13**). When comparing prosthetic performance on the obstacle to normative flat-ground patterns, the SoftFoot remained closer to human behaviour (RMSE: 0.51) than the carbon foot (RMSE: 0.62), suggesting better overall terrain adaptation.”*

Discussion *“Plantar pressure mapping showed this ground adaptation capabilities resembling those of the human foot. In contrast, prosthetic feet featuring carbon fibre laminates limit adaptability with smaller ground contact areas.”*

Methods *“To assess the similarity between mean plantar pressure distributions, the root mean square error (RMSE) was computed between the pressure maps of each prosthetic foot and that of the human foot on both flat ground and the obstacle. Calculations were restricted to the non-zero elements of the human foot’s mean pressure map on flat ground - the condition with the largest contact area - thus excluding non-contact regions. Mean pressure values were normalised by the subject’s body weight to account for the use of walking boots during prosthesis testing.”*

mC25-R2) **Minor Comment 25: Discussion:** *“. . . a more controlled forward body progression.” What does this mean? This is not logically supported by this study.*

a25-R2) Qualitative observation of the trials suggested that the user appeared to demonstrate improved gait control with the adaptive foot compared to the carbon foot, where pivoting behaviour on reduced contact areas and compensatory movements in both limbs were observed. However, we agree that the forward body progression was not directly evaluated in our study, so the expression “*controlled forward body progression*” cannot be quantitatively substantiated by our experimental data. This represents a limitation that would benefit from future investigation of the body progression using specific biomechanical assessments such as the centre of mass trajectory analysis during gait on uneven surfaces. We have revised the paragraph to focus specifically on the outcomes we measured whilst clearly indicating the observational nature of our comments regarding body progression control:

*“Plantar pressure mapping showed this ground adaptation capabilities resembling those of the human foot. In contrast, prosthetic feet featuring carbon fibre laminates limit adaptability with smaller ground contact areas. Visual inspection, in the authors’ opinion, suggested that the user might have improved control of forward body progression with the adaptive foot. Conversely, the carbon foot seemed to lead to pivoting on reduced contact areas (**Fig. 9a,d**), with apparent poor control of body progression and an increase in compensatory movements in both lower limbs. However, quantitative assessment of body progression control requires dedicated analysis in future studies.”*

mC26-R2) **Minor Comment 26: Discussion:** *“Results of the preliminary study demonstrated the advantages of the anthropomorphic prosthetic design, particularly the greater prosthetic ankle joint ROM. The main study confirmed these benefits and highlighted those for the contralateral sound limb.” Going back to my previous comment, it is not clear why there are effectively two studies presented in one paper.*

a26-R2) We thank the reviewer for this important question about the structure of our study. Initially, we presented a preliminary and a main study representing sequential stages of our evaluation process. As explained in our reply to Major Comment 1, for the sake of clarity, we have now revised the manuscript to present them as *Case Study I* and *Case Study II*, including the results of Case Study I into the main text alongside those

of Case Study II. The reason for this reorganization lies in the fundamentally different amputation types of the two prosthetic users who tested the SoftFoot Pro, which might warrant separate case study presentations. The first participant (Case Study I) underwent knee rotationplasty, meaning that the knee joint of his prosthetic side is actually an ankle joint, whilst the second one (Case Study II) had a transtibial amputation with osseointegration. These different amputation types and prosthetic interfaces represent distinct clinical populations with unique biomechanical characteristics. Therefore, we believe a separate evaluation is more appropriate to reflect each participant's distinct characteristics and biomechanics.

mC27-R2) *Minor Comment 27: Discussion: "Reduced contralateral limb loading with the SoftFoot led to smaller increases in the same-side stance knee flexion angle, torque (increase... " This statement is not logically supported, and requires more discussion.*

a27-R2) We acknowledge that the use of "same-side" for referring to the contralateral limb was ambiguous. The text has now been revised to eliminate any potential misunderstanding:

"Reduced forces acting on the contralateral limb with the SoftFoot led to smaller increases in contralateral stance knee flexion angle, torque (increase occurring mainly during load acceptance for stability and shock absorption), and power peaks compared to the Triton."

mC28-R2) *Minor Comment 28: Discussion: "Thus, the SoftFoot mitigated excessive compensations in the contralateral sound limb." This statement is not supportable without able-bodied references to define what "excessive" compensations are.*

a28-R2) As explained previously in answer (A2-R2), we have incorporated data from 12 unimpaired subjects into the revised manuscript. That sentence has been revised as follows:

"Thus, the SoftFoot mitigated excessive compensations in the contralateral sound limb. Compared to a carbon foot prosthesis, both limbs exhibited patterns closer to those of unimpaired subjects overall."

mC29-R2) *Minor Comment 29: Discussion: "They were able to step on obstacles naturally without having to carefully approach them with the prosthetic hindfoot or midfoot, as... " This statement is contradicted by the fact that users walked slower with the SoftFoot. It also appears evident in the videos that the users approached the uneven terrain slower and more cautiously. I think this statement is a stretch.*

a29-R2) We thank the reviewer for this consideration. We have revised that paragraph to more accurately reflect the participants' experience without overstating the naturalness of the gait patterns. The text now focuses on the subjective feedback from the participant of Case Study II regarding his confidence when using the SoftFoot, rather than making claims about natural stepping behaviour that are not supported by our measurements.

"The users provided highly positive subjective feedback regarding obstacle navigation with the SoftFoot. For instance, feedback from the participant of case study II highlighted enhanced confidence: "I felt more secure than with my own prosthesis." In contrast, when describing his conventional carbon fibre foot, he noted: "Going over obstacles with this foot feels sometimes a little bit unsafe. Users also appreciated the lightweight and anthropomorphic design of the SoftFoot, which offers a more natural foot shape, particularly beneficial for tasks like kneeling (Fig. 9c). This design feature may enhance users' body image and potentially encourage device embodiment and acceptance⁵⁹."

However, it will be very interesting in future work to quantitatively evaluate the cognitive load when using an adaptive prosthetic foot in an unstructured environment, as this would provide valuable insights into the mental effort required compared to the use of a passive carbon foot. We have added this as future work:

"However, participants reported fatigue from insufficient push-off propulsion in the SoftFoot, especially at higher walking speeds. We speculate that also the shorter stride length and reduced walking speed with the adaptive prosthesis in case study II might be related to this lack of propulsion (in addition to the fact that the subject was more familiar with the carbon foot, which was his daily-use prosthesis). Future design improvements will primarily focus on enhancing push-off propulsion through passive or active solutions at the ankle joint. Furthermore, a comprehensive assessment of dynamic stability remains to be conducted. Future studies will employ established metrics⁶⁰⁻⁶² to quantitatively assess it during locomotion on various surfaces,

comparing the SoftFoot Pro with conventional non-adaptive prostheses and unimpaired subjects. *Lastly, it will also be interesting to evaluate the cognitive load associated with our adaptive prosthetic foot during locomotion in unstructured environments.*"

In any case, the overall reduced gait speed with the SoftFoot Pro (both for level walking and obstacle negotiation) resulted from multiple factors, including insufficient propulsion at the ankle joint during push-off and the fact that the adaptive foot was not the participant's daily-use prosthesis. This point was discussed in the next paragraph: *"We speculate that also the shorter stride length and reduced walking speed with the adaptive prosthesis in case study II might be related to this lack of propulsion (in addition to the fact that the subject was more familiar with the carbon foot, which was his daily-use prosthesis)."* Given the results of the gait analysis with the SoftFoot Pro and its limitations, we are working towards an improved design to overcome push-off power release limitation. A preliminary design solution is described in ¹⁰, which will require validation through testing with prosthetic users.

Lastly, in the attached video of Case Study II, the steps on the obstacles were shown at reduced speed to focus on body motion. We realise that this may have been misleading, as the subject did not appear to slow down when approaching the uneven terrain during the experimental session. Hence, we have revised the corresponding video to show first the trial at normal speed, followed by a slowed-down view of the obstacle negotiation.

mC30-R2) **Minor Comment 30: Fig 8: "through modified walking boots" How were the boots modified?**

a30-R2) The walking boots were customised by incorporating prosthetic adapters screwed to the bottom of their soles to enable attachment of the prosthetic feet. This modification allowed unimpaired individuals to test the prostheses for comparative purposes. To help the reader, we have included them in Extended Data Fig. 2, which has been referenced in the main text (see *Results* and the last sentence of *Data collection and processing* subsection of *Methods*). In addition, they are shown in our previous conference publication (Ref. 53), as referenced in the last paragraph of the *Results* section:

"Lastly, when mounted under walking boots on an unimpaired individual⁵³ (see Extended Data Fig. 2), the adaptive foot showed negligible pressure at the midfoot during level walking due to its soft sole, with pressure peaks under the heel, metatarsal heads, and toes (Fig. 8b,e) resembling those of a sound foot (Fig. 8a,d)."

For clarity, we have revised the caption of Fig. 8, replacing "modified" with "customised":

"Able-bodied footprints (a,d,g,i) are from an unimpaired subject, while those of the SoftFoot (b,e,h,m) and of the carbon foot VariFlex (by O'ssur) (c,f,i,n) are from the same subject walking on the prosthetic feet through customised walking boots."

mC31-R2) **Minor Comment 31: Discussion: "Future design improvements will primarily focus on enhancing push-off ankle power generation." Describing pushoff ankle behavior as "power generation" is misleading because a passive prosthesis does not generate power. It can only store and return energy.**

a31-R2) We thank the reviewer for highlighting this point. We acknowledge the inappropriate use of the term "generation". We have amended the sentence to accurately reflect both passive and active solutions:

"Future design improvements will primarily focus on enhancing push-off propulsion through passive or active solutions at the ankle joint."

mC32-R2) **Minor Comment 32: Discussion: "In conclusion, this study proposed and validated the application of soft robotics principles..." Soft robotics is not discussed or applied in this study, how does the study validate this application?**

a32-R2) We acknowledge that our study does not explicitly discuss soft robotics principles. We have therefore revised the conclusion to remove the reference to soft robotics and focus on the characteristics of the SoftFoot Pro:

"In conclusion, the SoftFoot Pro combines stiffness for stability with flexibility for ground adaptation, surpassing the limited capabilities of commercial prostheses and research prototypes.[...]"

¹⁰Crotti, M., Pace, A., Grioli, G., Bicchi, A., & Catalano, M. (2025). Adaptive Ankle-Foot Prosthesis with Passive Agonist-Antagonist Design. IEEE International Conference on Robotics and Automation (ICRA), Atlanta, USA.

mC33-R2) **Minor Comment 33: Discussion: “. . . potentially reducing the risk of osteoarthritis in the contralateral limb and benefiting users’ long-term health.” Requires a citation that shows that more symmetrical loading reduces the risk of OA.**

a33-R2) We thank the reviewer for highlighting this omission. We have added appropriate citations to support this statement, including the reference previously cited in the *Introduction* (Ref. 14) and some additional studies documenting the relationship between increased loading on the intact limb in individuals with unilateral lower-limb amputation (i.e. load asymmetry) and higher risk of osteoarthritis. In the manuscript, we speculated that reducing gait asymmetries might decrease the risk of secondary complications typically associated with asymmetric gait patterns (see also the three additional references). We have revised the text to reflect the speculative nature of this potential benefit more cautiously:

“By redistributing the load to the prosthetic limb, the SoftFoot Pro improves gait symmetry and may potentially reduce the risk of osteoarthritis in the contralateral sound limb^{14,63–67}, benefiting users’ long-term health.”

The additional references are:

63. Gailey, R. (2008). Review of secondary physical conditions associated with lower-limb amputation and long-term prosthesis use. *The Journal of Rehabilitation Research and Development*, 45(1), 15-30. <https://doi.org/10.1682/jrrd.2006.11.0147>
64. Cutti, A. G., Verni, G., Migliore, G. L., Amoresano, A. & Raggi, M. Reference values for gait temporal and loading symmetry of lower-limb amputees can help in refocusing rehabilitation targets. *Journal of NeuroEngineering and Rehabilitation* 15, 61 (2018). <https://doi.org/10.1186/s12984-018-0403-x>
65. Brandt, A., Riddick, W., Stallrich, J., Lewek, M. & Huang, H. H. Effects of extended powered knee prosthesis stance time via visual feedback on gait symmetry of individuals with unilateral amputation: a preliminary study. *Journal of NeuroEngineering and Rehabilitation* 16, 112 (2019). <https://doi.org/10.1186/s12984-019-0583-z>
66. Runciman, P., Cockcroft, J. & Derman, W. A novel pivot ankle/foot prosthesis reduces sound side loading and risk for osteoarthritis: a pragmatic randomized controlled trial. *Prosthet Orthot Int* 46, 258-266 (2022). <https://doi.org/10.1097/pxr.0000000000000079>
67. Hu, J., Ding, Z. & Bull, A. M. J. Alterations in Muscle Coordination to Reduce Knee Joint Loading for People with Limb Loss. *Annals of Biomedical Engineering* 53, 935-945 (2025). <https://doi.org/10.1007/s10439-025-03682-6>

mC34-R2) **Minor Comment 34: Supplementary Table 12 – Statement S1 has no response for the SoftFoot Pro.**

a34-R2) We thank the reviewer for this observation. This missing response was previously acknowledged in the *Results*, where we noted: “The carbon foot achieved the highest SUS score (92.5 (Triton) vs. 67.5 (SoftFoot)), although the participant omitted to reply to the first SUS statement for the SoftFoot (Supplementary Table 12) - perhaps an oversight.”

We interpreted this as an oversight on the part of the participant. However, we recognise that this may have compromised the validity of the questionnaire. Therefore, we have removed the SUS from the manuscript. In future studies, we will conduct these kinds of qualitative assessments more carefully to ensure complete data collection.

Reviewer #1

The manuscript has been revised as suggested. The manuscript can be accepted for publication.

Thank you for your positive evaluation and for acknowledging the revisions we made in response to the comments we received.

Reviewer #2

Dear authors, Thank you for addressing the comments in my first review. In my opinion, these changes improved both the readability and the paper's overall impact. I have no additional major comments. However, I would like to ask the reviewers to address the following minor comments.

Thank you for appreciating the revisions we made and for recognizing the improved overall quality of the manuscript.

mC1-R2) *Minor comment 1: Figure formatting - Several figure captions, including Fig. 4 and 7 are slightly cut off by the page margin.*

a1-R2) We have revised the figure formatting.

mC2-R2) *Minor comment 2: Supplementary Fig. 1 Missing legend.*

a2-R2) We have added the legend in Supplementary Fig. 1. Thank you for noticing it.

mC3-R2) *Minor comment 3: Figure Text Sizes - On all figures it would be helpful for the authors to increase the text size that it is easier to read.*

a3-R2) We have increased the font size of the text in all figures as suggested, also in accordance with the journal's guidelines.

mC4-R2) *Minor comment 4: Missing Indents - Line 233 and Line 380.*

a4-R2) We have added the indents.

mC5-R2) *Minor comment 5: Anatomy clarification - I may be incorrect in assuming the author's intended design, but I believe the work "aponeurosis" in line 391 should instead refer to the full plantar "fascia".*

a5-R2) We thank the reviewer for pointing this out. The text has been revised by replacing "aponeurosis" with "fascia," including in the caption of Fig. 3.

Comments

The manuscript titled “The SoftFoot Pro: an Anthropomorphic and Adaptive Soft Robotic Prosthetic Foot” presents a novel approach to prosthetic foot design, particularly in its anthropomorphic and adaptive characteristics. However, the following comments and queries are raised for consideration:

1. Theoretical formulations are essential for understanding the various mechanical behaviours of the prosthetic foot. The current manuscript presents only experimental results. Additionally, the measurement procedures are not described in the Methods section, which would aid reader comprehension and reproducibility.
2. The theoretical modelling of the sole’s mechanism is not provided. It is unclear how the individual links were designed specifically for this prosthetic foot.
3. No design calculations are included, particularly regarding the selection of spring stiffness, which is crucial for performance.
4. If the sole is described as flexible, how can it simultaneously be inextensible? This apparent contradiction needs to be clarified.
5. How was the stability of the prosthetic foot evaluated? Information on assessment methods is lacking.
6. What is the functional role of links 7 and 8? They appear to serve primarily aesthetic purposes, and their contribution to the overall mechanism should be clarified.