Title: Design of a suit to deliver a plantarflexion torque at the ankle.
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Topic: Designing a suit to initiate plantarflexion and producing a prototype.

The assignment was provided by the Department of Biomechanical Engineering. They asked for a suit that applies a torque to the ankle joint. They wanted a prototype, which they could use in research into interference at the ankle during gait. This research could for example find the optimal moment of the gait cycle to apply a torque, so that the metabolic cost of the wearer would be the lowest.

The prototype that was produced for this assignment consists of an electric drive to provide a force. A Bowden cable was used to transmit this force to a torque at the wearer of the suit. This Bowden cable is lightweight, allowing the suit be of a low weight as well. *Figure 1* shows what this Bowden cable looks like.

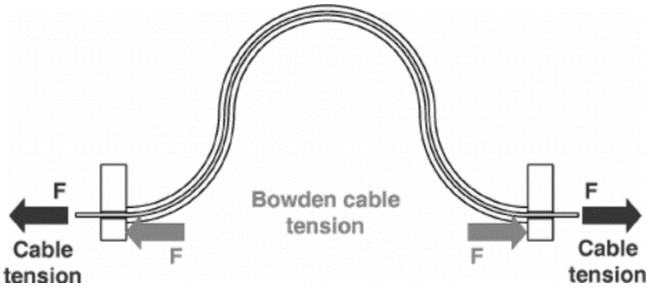

Figure 1: Bowden cable [a1]

The Bowden cable is attached to the wearer by means of a suit. The suit consists of an elastic legging with non-elastic straps sown unto it. The force, applied at the heel and the calf, can be transferred to the pelvic area by means of these non-elastic straps.
The used Bowden cable consists of an outer sheath and an inner cable. This inner cable is attached to the heel and the outer sheath is attached at the bulk of the calf. To attach the outer sheath, a calf piece was 3D printed. This piece distributes the pressure due to its larger area. A render of this calf piece can be found in *figure 2*.

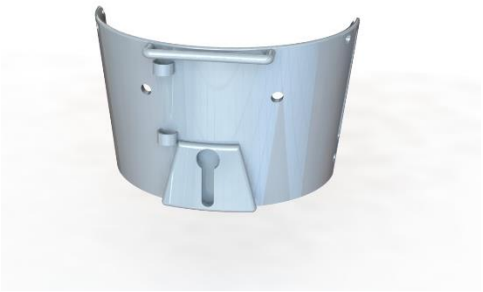
Figure 2: Render of the calf piece

The prototype accounts for adjustability in several ways. Adjustability was deemed important because the assumption was that numerous people were going to wear the prototype for the research. The straps will be referred to by their numbers as shown in *figure 3*. The waist belt (1) of the suit is adjustable in size. The straps that lead to the pelvic area (2)(3) are adjustable in their position. The straps that lead through the knee joint (5)(6) are adjustable in their position as well. Lastly, the lowest strap (7) is adjustable in its size. Furthermore, the calf piece is adjustable in its position.

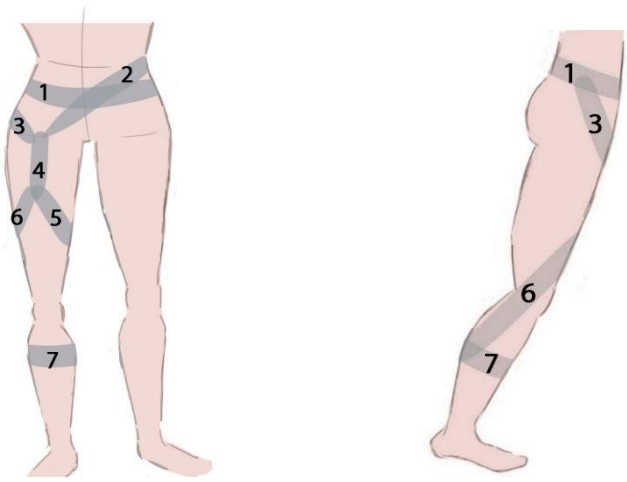

Figure 3: Straps in the force path

Experiments were conducted with the prototype, to determine whether the prototype was fit for the research it was intended for. This prototype can be seen in *figure 4*.
These experiments have shown that the force at the user was able to stay practically constant. On the other hand, the suit also showed a large displacement, discomfort and loss of forces. These disadvantages were due to the materials of the suit and friction in the Bowden cable. There are several ways to tackle these problems. To increase user comfort, padding can be added to the suit. To decrease displacement, different materials could be considered. Furthermore, to reduce the friction between the outer sheath and the inner cable of the Bowden cable, the actuator module could be positioned higher.

Figure 4: Prototype

A proposal for commercial use of this product was provided too. This commercial product was designed for physically healthy individuals, just like the prototype. Furthermore, the focus was laid on recreational use, to be able to create a personalized style. This commercial product can be found in *figure 5*.
Some differences between the prototype and the commercial product proposal is the use of padding and recesses, a lightweight actuator module which can be carried in a backpack and integrated

Bowden cables which will reduce friction.

Figure 5: Final drawing of the commercial product

References

[a1] Schiele, A; Letier, P; van der Linde, R; van der Helm, F. (2006). “Bowden Cable Actuator for Force-Feedback Exoskeletons”. Proceedings of the 2006 IEEE/RSJ International Conference on Intelligent Robots and Systems. (October 2006).