A Passive Assistive Exoskeleton to Increase Running Efficiency

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Abstract

A Valparaiso University engineering senior design team is developing a lower-body exoskeleton prototype to increase the user's running efficiency by 2%. The device is passive, which means that all elements of the system are powered by the user's motion and impact with the ground. This is done via elastic fabric elements and spring steel actuators that are attached at the user's hip, knee and ankle. The device's effectiveness can be tested using a VO2-max test in which the test subject runs on a treadmill at a constant pace with and without the device. The test records the amount of oxygen consumed by the user during the trials, which is directly correlated to the calories burned by the user during the trials. Due to the onset of COVID-19, the team was unable to test the device in Spring 2020. However, data from the VO2-max test of a previous prototype was available and was used to develop a repeatable analysis pipeline to enable the research team to rapidly determine if changes to the design are beneficial. The pipeline uses the output data from the VO2-max test to determine if there is statistically significant evidence that the user running with the device is more efficient than the user running without the device. It also compares the efficiency of the device under different testing parameters as elevation and speed changes throughout the VO2-max test. Analysis was performed using Python and the proprietary software used to record data from VO2-max tests. This pipeline is intended to aid in the continued development of the prototype once social-distancing conditions ease.

Introduction

This project is a continuation of a project started in 2017 by myself and two other undergraduate research students under the guidance of Professor Craig Goehler. A first prototype was built and then presented on at the 2018 American Society of Biomechanics Conference. The original project attempted to develop an ankle-based exoskeletal device "that will improve the efficiency associated with moderate physical locomotion activities and lessen the strain on involved joints". However, it was believed by the group to have been ultimately unsuccessful as initially testing indicated that it made running ≈ 40% less efficient. The new project expands on the original by building a passive exoskeleton for the whole lower body, not just the ankles as the researchers believe there is untapped efficiency potential by incorporating other joints.

The new iteration of the project is being done by a Senior Design team, under the guidance of Professor Reva Johnson, with the goal to develop a passive assistive exoskeleton to increase the efficiency of moderate running by 2%. Both iterations were designed to be tested using a VO2-max test which calculates how much energy a runner is expending at a given instant based on their oxygen consumption. In order to quickly analyze the results of the VO2-max test, a computational pipeline was desired that would allow the team to take the raw output of the test and input it into a Python code to be able to quickly see results of the test. The team wanted to know the following things:

1) Was the device more or less efficient than running without it?
2) Did the device perform better at certain speeds or elevations?
3) Did the comparative efficiency vary over time?

Due to the onset of social-distancing caused by COVID-19, the VO2-max test was unable to be performed on the new design. However, the pipeline based on the old data will be able to quickly calculate results for the new design once a VO2-max test is performed. The development of the pipeline was done under the guidance of Professor Tiffany Kolba.

Designs

Figure 1. The original ankle-based design created by research team in 2018.

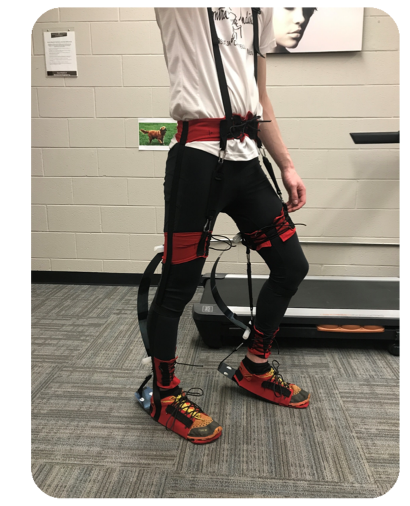


Figure 2. The new design created by the Senior Design team in 2020.

Testing

The setup for the VO2-max test requires the runner to run on a treadmill while wearing a mask that measures the intake and expulsion of oxygen. The runner is initially guided through a series of speed and elevation changes ranging from 0 to 5.0 mph and from a 0 to 18% gradient over a 20-minute testing interval. The runner then does the same protocol with the device (image to left). The variables recorded during the test are the subject's heart rate, total Kcals used, the speed of the treadmill and the elevation of the treadmill. In 2018, two baseline tests were done and were compared to a single test with the device.

Analysis

As the VO2-max test output the total Kcals used during the test, it didn't display the change in Kcals at a given point during the test (i.e., the energy consumption for a given instant). The group believed that the efficiency of the device might vary throughout the test, so a new variable was developed using the time-stamp and total Kcal used value for each data point to calculate the Kcals consumed at a given moment. This new variable Kcal/min was then used in the efficiency calculations and other comparisons between the device and baseline tests.

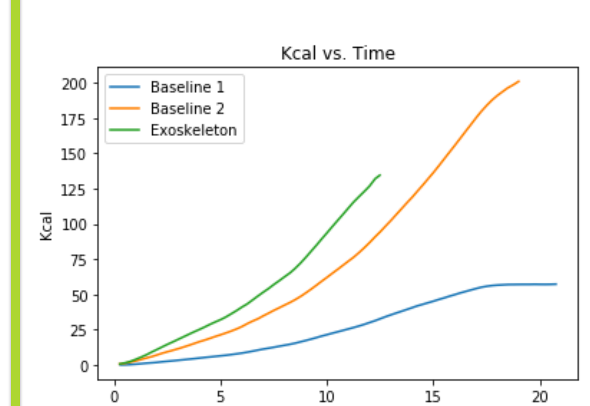
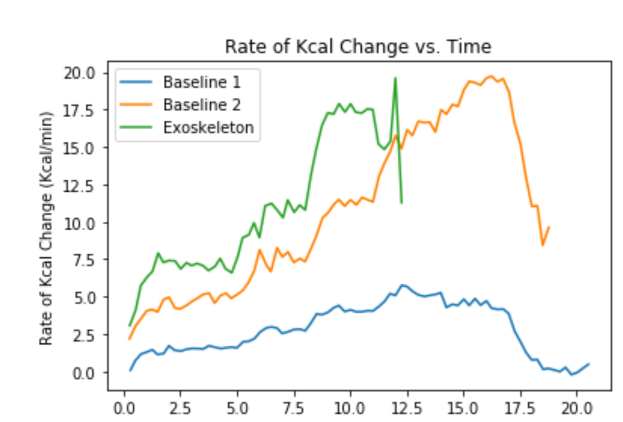


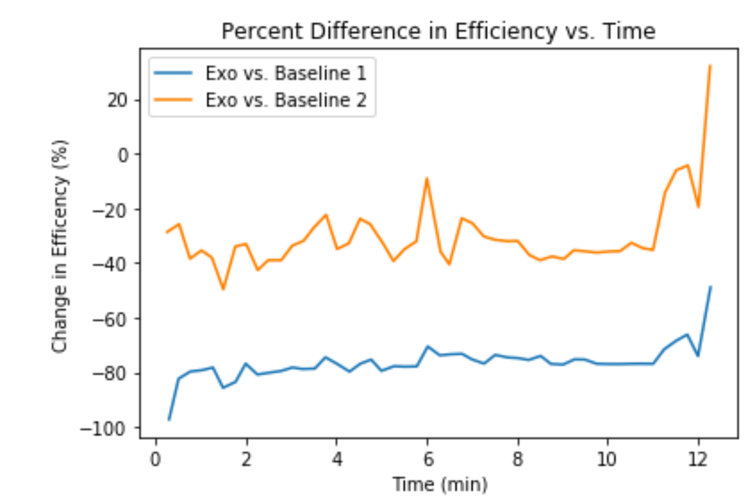
Figure 3 (left). The Kcal variable from the raw test output that shows the cumulative Kcal consumption.

Figure 4 (right). The Kcal/min variable derived from the slope of total Kcal consumption and each time-stamp.



Results

Using the created Kcal/min variable, the percent difference in efficiency between the exoskeleton device and the baseline was calculated at each point throughout the test. A two-sample t-test was used to determine if the results were statistically significant (points were not matched due to the differing lengths and inconsistent time points of the trials). The pipeline also produces the percent differences in efficiency for each 5-minute interval so the researchers can examine a specific interval easier.

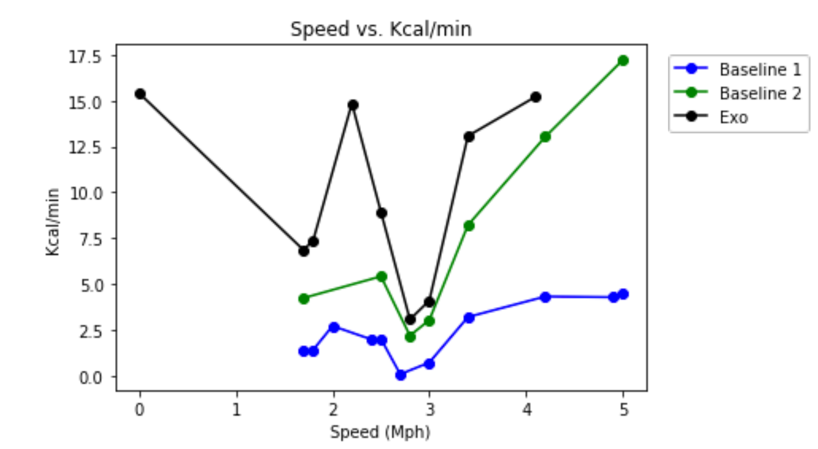


The median efficiency difference between Exo and Baseline 1 is: -76.9%

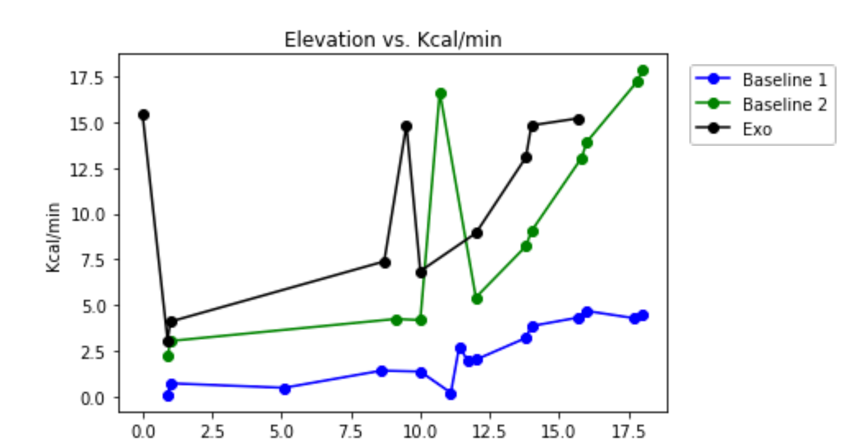
The median efficiency difference between Exo and Baseline 2 is: -33.7 %

Statistical Results for difference between means of Baseline 1 and Exo t-test: t-statistic=-14.8, p-value=1.65e-29)

Statistical Results for difference between means of Baseline 2 and Exo t-test: t-statistic=-0.3, p-value=0.80)



The researchers were very interested in how efficiency changed with speed so a graph (image to left) was developed that shows energy consumption (Kcal/min) at each treadmill speed (rounded to one decimal place). It is interesting to note that the graph indicates that energy consumption was highly variable with speed.



Similarly, the team wanted to know how elevation affected energy consumption. The resulting graph (image to left) revealed that there may have been an elevation where the device did make the user more efficient compared to the second baseline test. This elevation was likely between 10 and 12.5% gradient.

Conclusion

An analysis pipeline was built in Python that is able to take raw VO2-max testing data and output useful graphs and statistical analysis. Importantly, the results show how efficiency changes over time, speed and elevation to give researchers further insight into the strengths and limitations of their design. When testing of the latest prototype resumes, the researchers will be able to use this pipeline to quickly determine how their design has altered the runner's energy consumption.

Future developments of this pipeline would be to expand it to automatically average the results of several baseline and exoskeleton test results so a larger sample size can be examined. The testing procedure could be altered to have the subject move over a wider variety of speeds and elevations to further examine the effect on energy consumption.

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