Extrusion Printhead for the Fabrication of Helical Shape Memory Polymer Artificial Muscles for Spaceflight

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Overview

This research is motivated by the need for bio-assistive devices, such as exoskeletons, to aid astronauts suffering from microgravity induced muscular atrophy. Herein, a compact, lightweight printhead system was designed to extrude helically structured shape memory polymers (SMPs) to be used as artificial muscles (AMs) during spaceflight. To verify the printhead design, artificial muscles were extruded, programmed, and actuated using polylactic acid (PLA) as the SMP material. The novel design of the printhead eliminates the need for a substrate or support materials to fabricate helical structures and therefore furthering manufacturing techniques to create artificial muscles from a variety of polymers with shape memory effects.

Introduction

Polymer-based AMs are currently fabricated by twisting polymer threads to form helical coils or through traditional three-dimensional printing methods. These fabrication methods are complicated and require large, heavy equipment making them unsuitable for spaceflight. The printhead system developed during this research was designed to be lightweight, compact, and simple to operate for missions to deep space through the development of an internal mandrel that shapes and supports the SMP during extrusion by accurately controlling solidification status of the polymer melt within the printhead.

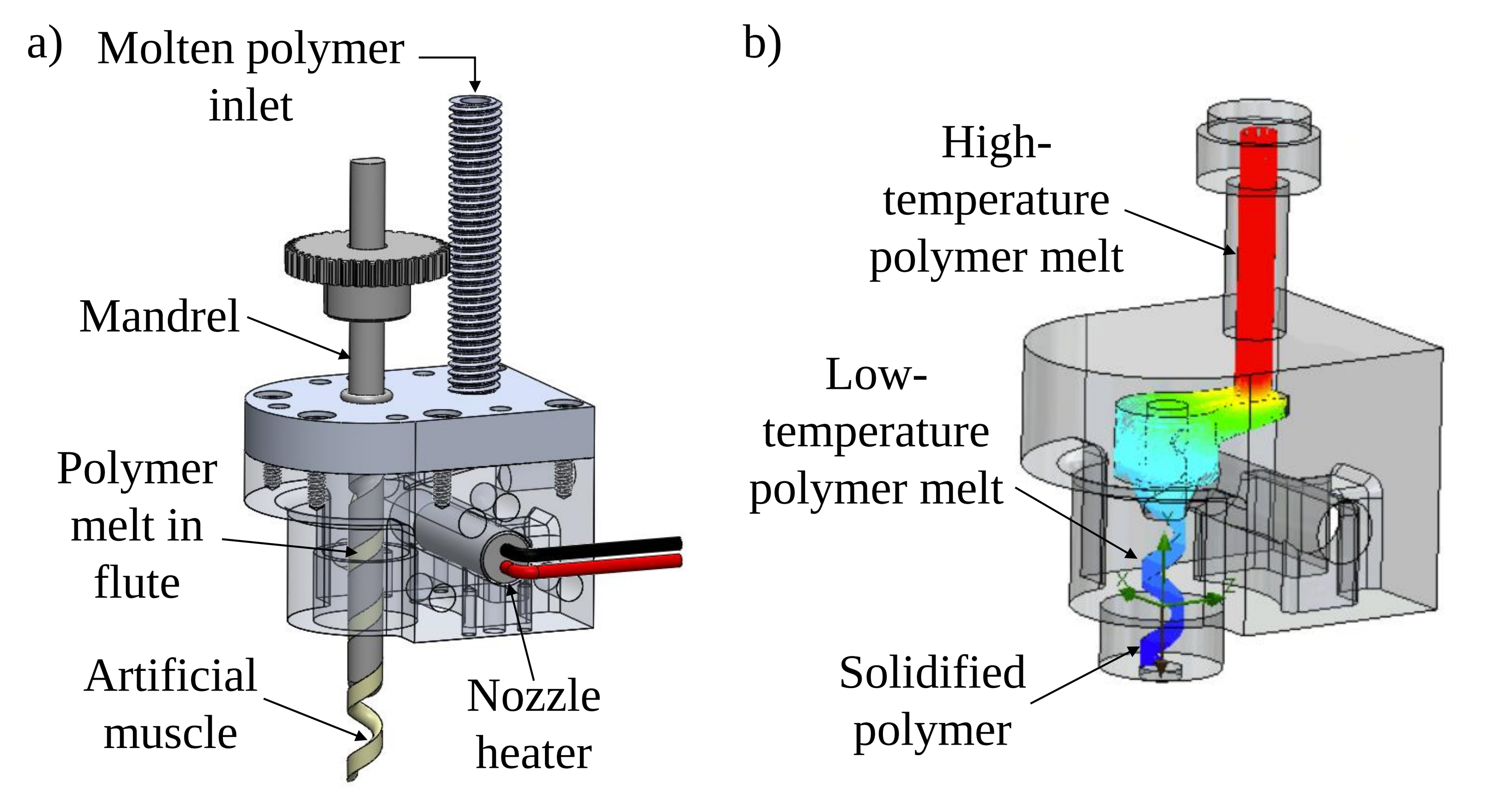

Fig. 1. a) Helical extrusion and AM support through internal mandrel and **b)** polymer solidification through flutes of mandrel.

Methods

Printhead design through simulation:

Table 1. Orthogonal design and results

Sim.	l_a (mm)	α (°)	l_n (mm)	h_s (mm)	v (CV)
1	10	0	14	>14.0	8.9
2	10	11	19	10.77	11.5
3	10	22	24	7.091	8.3
4	13.5	0	19	10.70	11.5
5	13.5	11	24	7.432	8.2
6	13.5	22	14	>14.0	9.0
7	17	0	24	6.95	7.9
8	17	11	14	>14.0	9.9
9	17	22	19	10.77	10.5

Artificial muscle extrusion experiments:

Table 2. Artificial muscle printing parameters

Parameter	Unit	Value
Reservoir temperature	°C	215
Nozzle temperature	°C	130
Fan flow rate	m^3/s	$7.55x10^{-4}$
Inlet pressure (gauge)	kPa	6.895

Artificial muscle contraction experiments:

Table 3. Contraction temperatures and times

Step	Temperature (°C)	Time (min)
Programming	64	2
Contraction	70	1.5

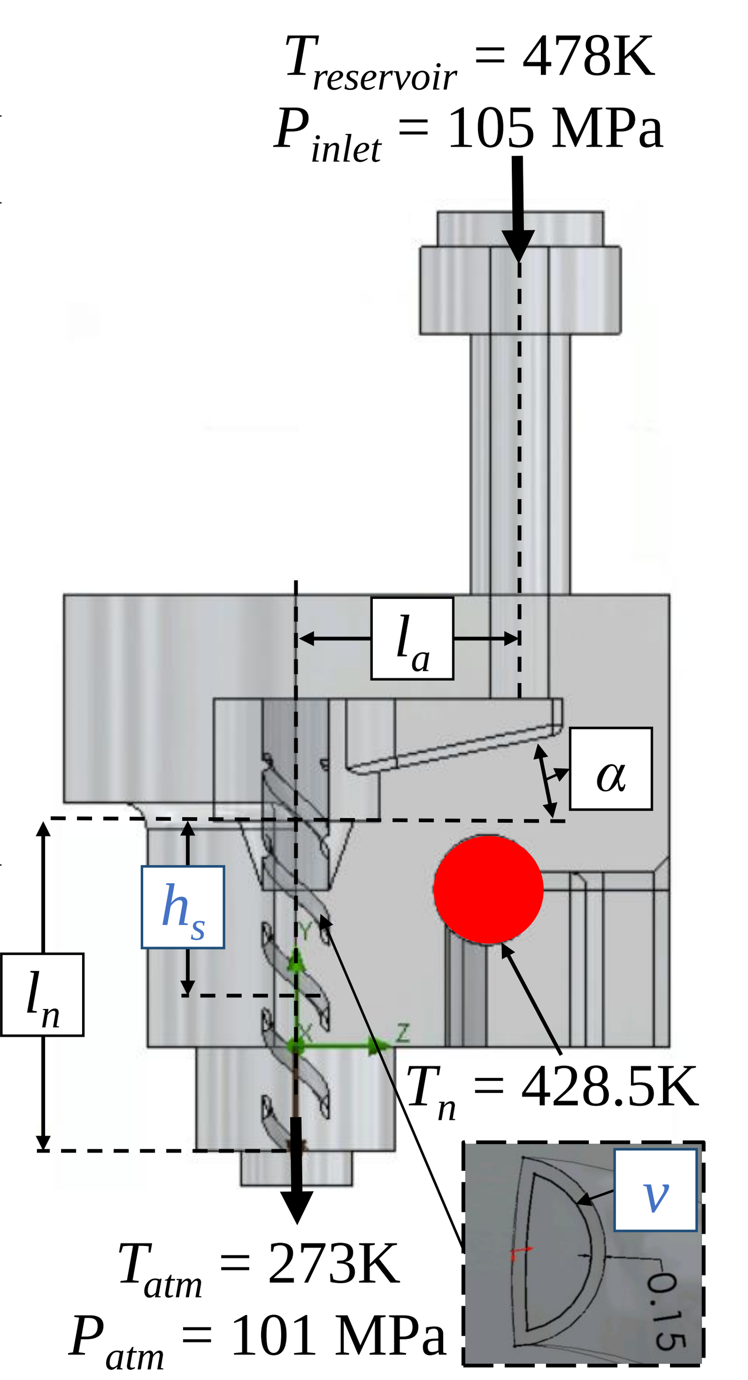

Fig. 2. Critical geometries, solidification height (h_s), velocity profile (v), and parameters for polymer flow simulation of printhead design.

Results

Final design and assembly of printhead

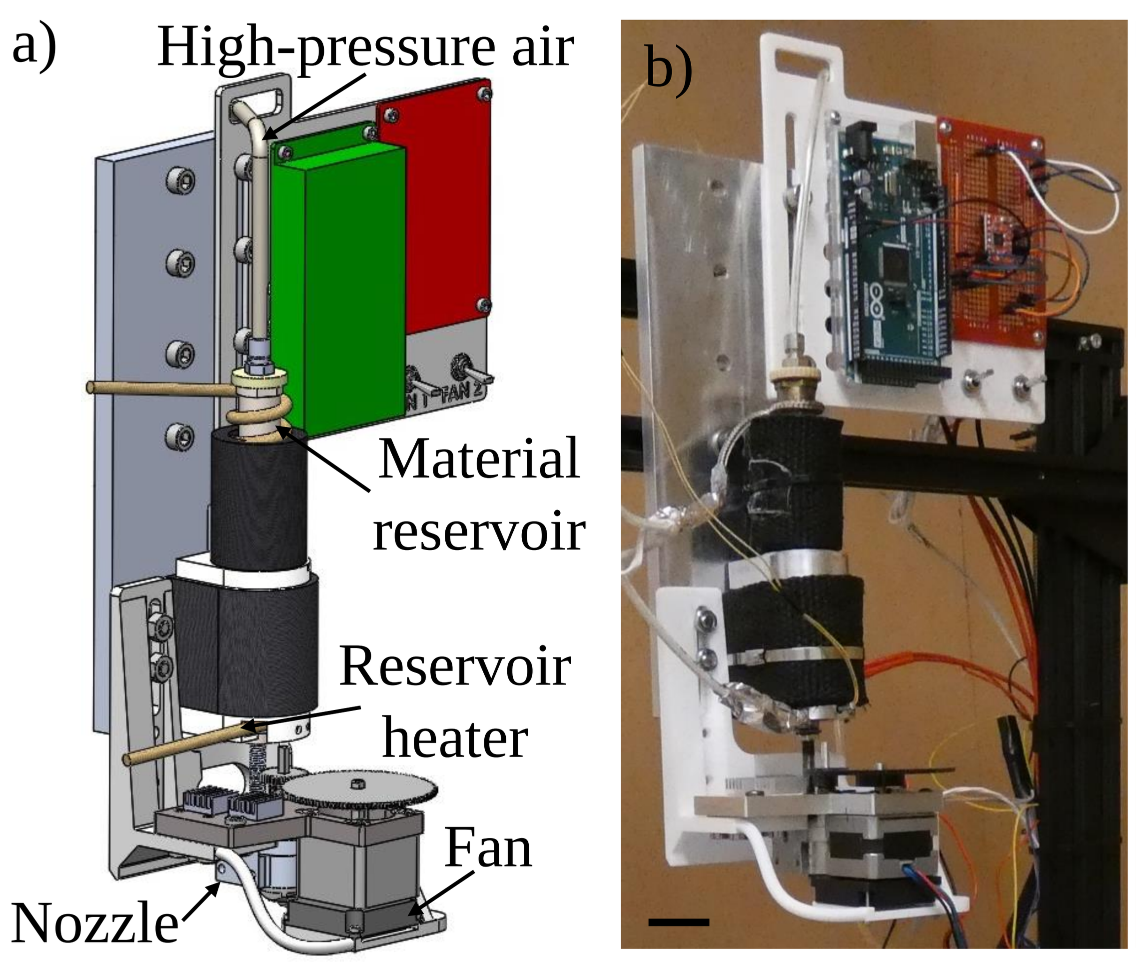

Fig. 3. a) Computer aided model and **b)** final assembly of printhead system (scale: 25 mm).

Artificial muscle extrusion and measurements

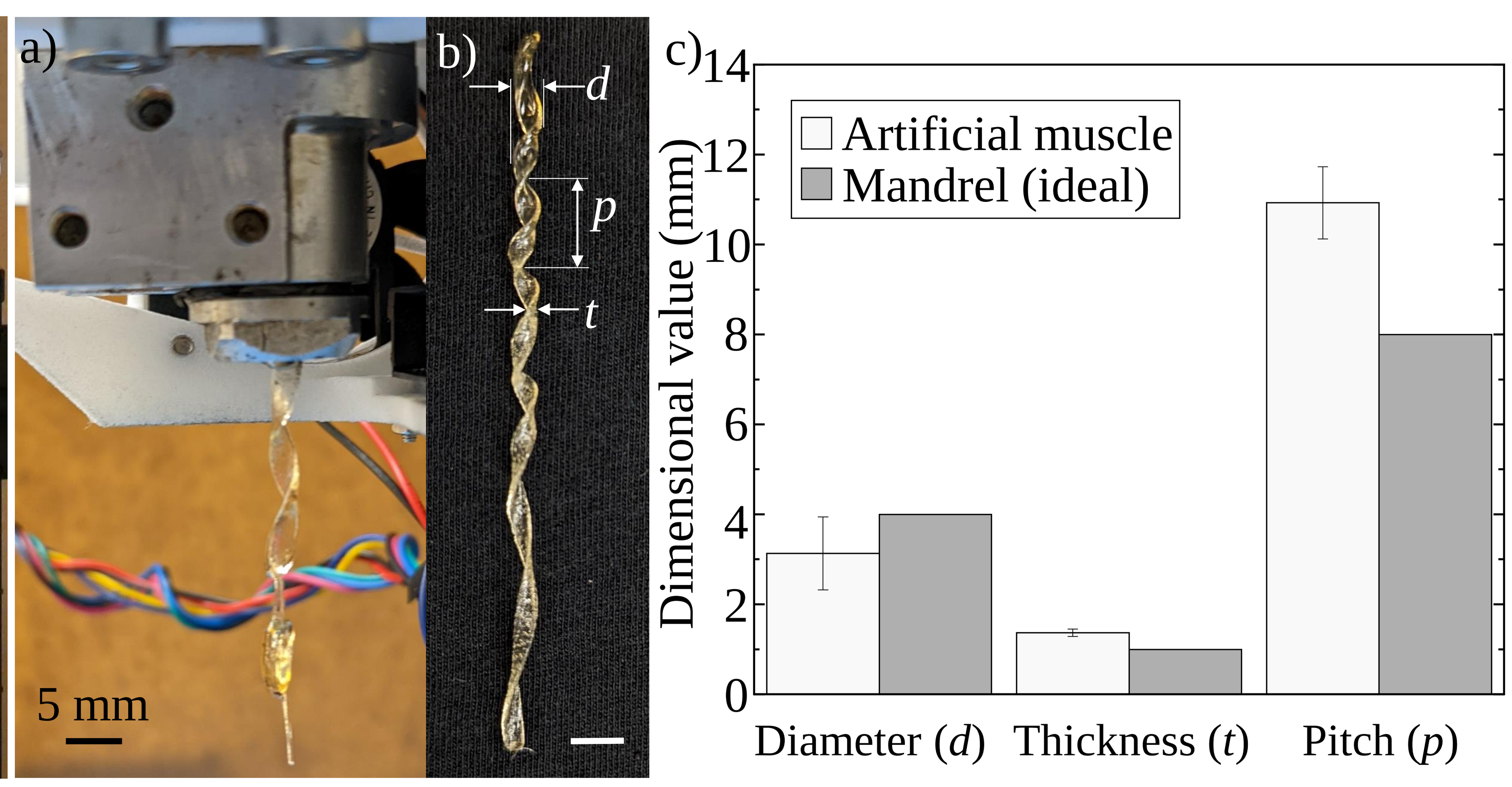

Fig. 4. a) Helical AM extrusion, **b)** printed helical AM and dimensions of interest including muscle diameter (*d*), pitch (*p*), and thickness (*t*) (scale: 5 mm), and **c**) average AM diameter, thickness, and pitch compared to the respective dimensions of the mandrel.

Artificial muscle contraction

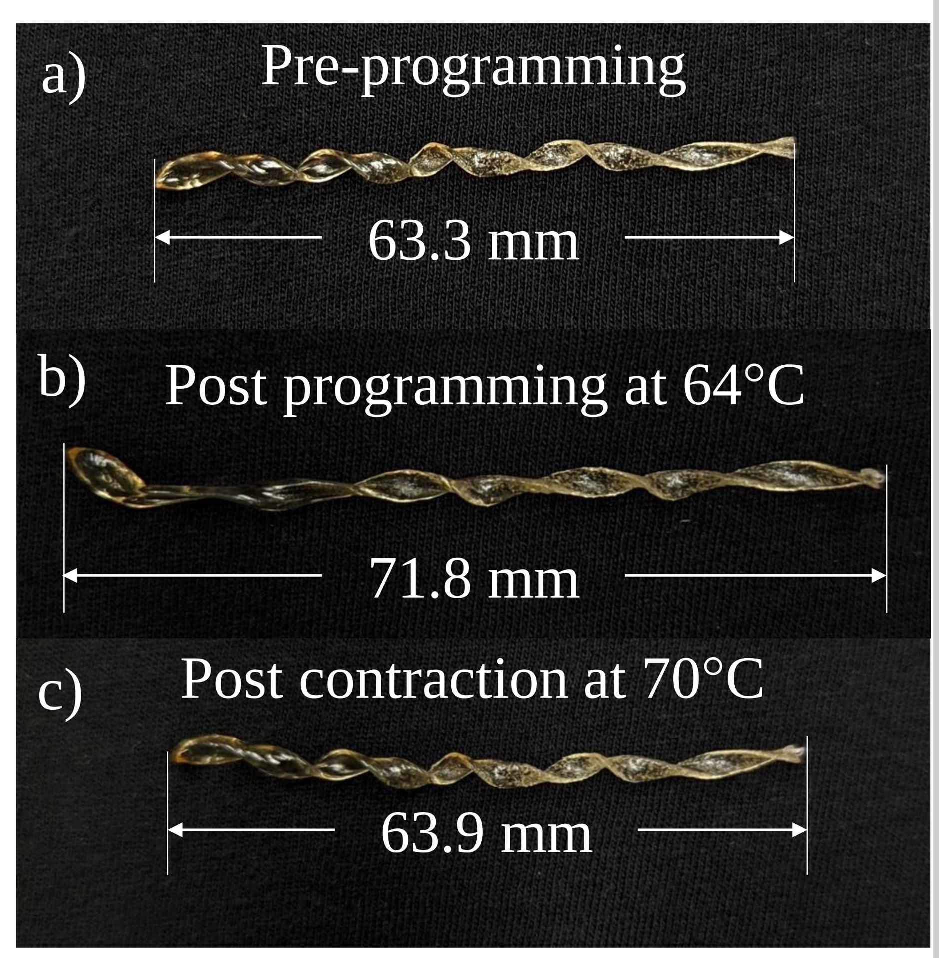

Fig. 5. Artificial muscle **a)** initial length, **b)** length post programming, and **c**) length post contraction.

Conclusions

- A printhead system was designed to manufacture SMP helical AMs for spaceflight.
- The extrusion, measurement, and contraction of PLA helical AMs validates the internal mandrel design.
- Other thermal actuated SMP materials could be used to fabricate a wide variety of AMs.
- The mechanism used to solidify and support AMs without the need for a substrate could be used to fabricate other complex structures.

Acknowledgements

- This material is based upon work supported by the National Aeronautics and Space Administration under Cooperative Agreement No. AWD-01-00003025.
- Special thanks to Lily Raymond, Evan Doering, and Joshua Wood for their contributions to this research.