Responses to Reviewers

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Title: Smart Thermally Actuating Textiles

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We appreciate the helpful and thoughtful comments from the reviewers. We believe that we have addressed all of their comments and consequently improved the quality of our manuscript. Specifically, we added a discussion on the lifetime of STATs, clarified the robustness of STATs when exposed to water and characterized STAT durability during 10 cycles of repeated machine washing, and tested STAT robustness when exposed to 10,000 cycles of repeated bending. The changes and detailed explanations are included in the responses to the reviewers below.

Reviewer #1:

1.0: The work described in the manuscript present a smart thermally actuating textile which was made of sensing and heating elements. author used a highly customizable, scalable, and simple manufacturing process to fabricate the smart thermally actuating textiles. The smart thermally actuating textiles can feedback the external temperature change by pressure. The excellent actuation performances, scalable and accessible production approach enables bright applications prospect. The overall presentation is good, while the authors should clarify the following issue before the paper can be accepted for publication.

We thank the reviewer for their kind feedback and thoughtful comments. The reviewer expressed concern about characterizing the textile performance for washing and bending as well as additional proofreading, which we have addressed below.

1.1: Detailed and carefully work has been showed in this paper, lots of characteristics demonstrated in manuscript and supporting information. However, as a textile material there are some based performances should be satisfied such as washing and bending stability. Please show the washing and bending stability of this STAT.

We thank the reviewer for their kind feedback. Based on the reviewer's suggestions, we have characterized the washing stability and bending stability of the STAT components. We detail these results in a paragraph added to the main text on Page 9, Paragraph 3 (added text italicized):

"STATs are developed for wearable applications, so we characterized their durability when exposed to repeated washing, repeated bending, and extreme applied forces to provide insight into the STAT lifetime during scenarios potentially encountered during typical clothing use. Because STATs are built on a TPU-coated textile substrate, they have intrinsic water resistance, enabling washability without degradation (Figure S20). Due to the compliant and resilient nature of textile materials, STATs are robust and do not exhibit degradation after repeated bending and under extreme applied forces (Figure S21, S22)."

To support these claims, we included additional figures and discussion in the supporting information (added text italicized):

"5. STAT Lifetime and Closed-Loop Control
To determine the STAT lifetime, we evaluated several durability parameters and evaluated lifetime cycling with closed-loop control. Additionally, we further characterized the environmental effect on closed-loop control.

5.1 STAT Wash-fastness

The water resistance and wash-fastness were studied to evaluate STAT durability for wearable applications. Two 15-line STAT modules were fabricated with soft sensor connections and sealed fastener connections at the heaters. The heater resistance was measured with a multimeter (26III, Fluke Corporation). The baseline sensor capacitance as well as capacitance under applied pressure, where a flat STAT was pressurized with 2.1 kPa using a weighted square indenter placed upon the sensor location, were measured with an LCR meter (380193, Extech Instruments). The STATs were subsequently washed in a home washing machine (WF45R6100AW, Samsung) using settings of "delicate," temp=1, spin=1, rinse=1, and soil=1 with a commercially available consumer laundry detergent (Tide Free and Gentle, Proctor & Gamble) as used in other studies for its absence of fragrance and dyes (Figure S20A).[9] Samples were placed in mesh bags during laundering and 727 grams of assorted household textiles were incorporated to meet the minimum load weight. After washing, the samples were air dried and heater resistance and sensor capacitance were measured. This washing test was repeated for 10 cycles, chosen as a benchmark based on the washing durability of the "Google Jacquard Jacket," [9,10] a commercially available consumer wearable device that is reported to remain operational for up to 10 machine wash cycles. The normalized capacitance and resistance change are plotted, where C_0 and R_0 are the initial capacitance and initial resistance measurements, respectively (Figure S20B, C, D). Error bars represent combined uncertainty from the measurement device accuracy error and the statistical variance between three measurements averaged for each data point. Because of the TPU coating, the STATs are inherently water resistant, and STATs exhibit no degradation due to washing. Although STATs are an initial proof of concept, their robustness to washing illustrates they have a care lifetime on par with that of consumer wearables.

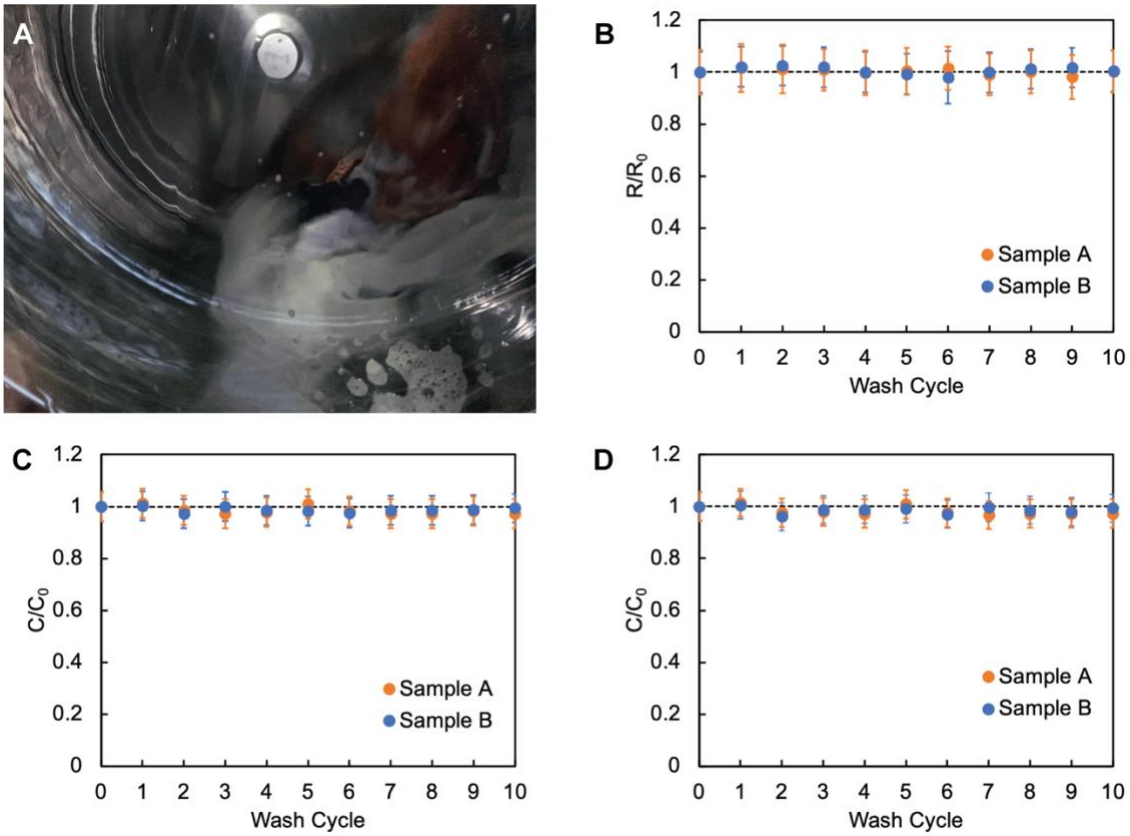

Figure S20. *The robustness of STATs to machine washing; photo of STATs in a wash cycle shown in (A). The normalized resistance of the STAT heater (B) and the normalized baseline capacitance (C) and pressurized capacitance (D) of the STAT sensor as a function of wash cycle highlight the absence of statistically significant component degradation after 10 wash cycles.*

5.2 STAT Robustness under Repeated Bending

In order to evaluate STAT robustness to bending, the resilience was studied using one 15-line STAT module with soft sensor connections and fastener connections at the heaters. The STAT was bent manually to a 90º angle (Figure S21A). The heater resistance was measured with a multimeter (26III, Fluke) and the baseline sensor capacitance as well as a pressurized capacitance, where a flat STAT was pressurized with 2.1 kPa using weights at the sensor location, was measured with an LCR meter (380193, Extech). This bending test was repeated for 10,000 cycles of bending, with measurements taken after 1, 10, 100, 1000, and 10,000 cycles. The normalized capacitance and resistance change were plotted, where C_0 and R_0 are the initial capacitance and initial resistance measurements, respectively (Figure S21B, C, D). Error bars represent device accuracy error and measurement error. Because of the flexible nature of the textile materials, the STATs do not exhibit any degradation due to repeated bending.

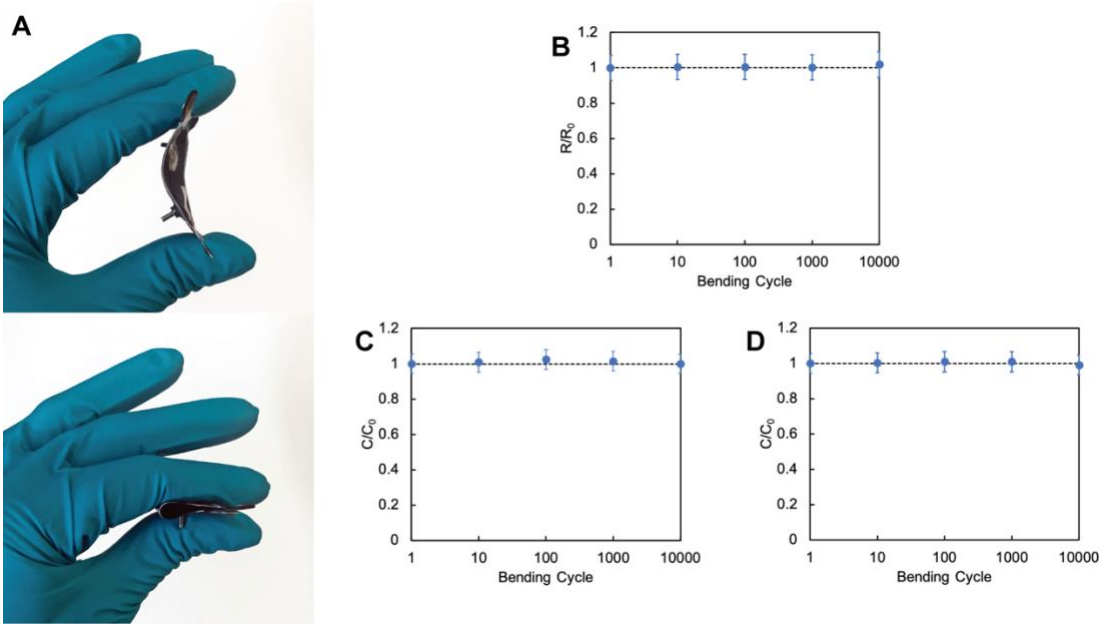

Figure S21. *The robustness of STATs to bending, performed as pictured in (A). The normalized resistance of the STAT heater (B) and the normalized baseline capacitance (C) and pressurized capacitance (D) of the STAT sensor as a function of wash cycle highlight that component degradation does not occur during 10,000 cycles of bending.*

1.2: There are many errors in detail in the manuscript, and the authors need to carefully review the entire manuscript to ensure that they are corrected. For example, "Figure 1" in page 5, line 11 was blod but regular in line 24.

We thank the reviewer for this comment. We have bolded the figure references according to the instructions in the *Advanced Materials Technologies* Word document template, which states: "Please make the first reference to a display item bold." Because the reference in line 5 is the first reference, it is bold, while we have left the reference at line 24, and others, regular. However, we reviewed the rest of the manuscript and the supporting information and corrected any typographical, grammatical, and formatting errors.

References added to the supporting information following our response to Reviewer 1:

L. Eskandarian, E. Lam, C. Rupnow, M. A. Meghrazi, H. E. Naguib, *ACS Appl. Electron. Mater.* **2020**.

I. Poupyrev, N. W. Gong, S. Fukuhara, M. E. Karagozler, C. Schwesig, K. E. Robinson, *Conf. Hum. Factors Comput. Syst. - Proc.* **2016**, 4216.

Reviewer #2:

2.0: The manuscript "Smart Thermally Actuating Textiles" introduced a thermally actuated robotic textile which was driven by liquid-vapor phase change. The smart textile was fabricated by scalable processes including laser cutting and heat pressing with customizable structures and functions. The authors have characterized the pressure-temperature relationship for the saturated fluid, the effect of heater geometric, pressurization response speed, and the variation in environmental conditions. Afterward, the smart textile was demonstrated with prototypes ranging from individual modular samples to connected arrays of varied geometries. The concept of this work is interesting, which could find wide applications in the soft robotic field. This manuscript is well written and prepared.

We thank the reviewer for their reading of our manuscript and for their kind and constructive comments. The reviewer raised concerns about STAT reliability in terms of water resistance and lifetime which we have led us to improve our manuscript.

2.1: However, there is one concern about the reliability of the smart textile. How about the water resistance of the textile during wearing, and how long about the lifetime of the devices?

We appreciate this thoughtful comment. The STAT is inherently water resistant because of the TPU membrane imparted onto the fabric. We have updated the main text to clarify this detail on Page 9, Paragraph 3 (added text italicized):

"Because STATs are formed on a TPU-coated textile substrate they have intrinsic water resistance, enabling washability without degradation (S20)"

Additionally, as mentioned in our response to Reviewer 1 above, we have studied and included the prolonged water resistance of the STAT in a machine-washing test as an extreme example. Lastly, we added an extreme applied force test to highlight the STAT robustness in the supporting information (added text italicized):

"To further highlight the robustness of STATs, indicative of their long lifetime, a 15-line STAT with soft sensor connections and fastener heater connections and was driven over with a 1605 kg pickup truck (Figure S22). Similarly, due to the compliant nature of the textile and the two-dimensional profile inherent from fabrication, the STAT exhibited no degradation. The heater resistance changed by less than 1%, while the baseline capacitance changed by only 1.5%.

Figure S22. A STAT module being driven over by a 1605 kg pickup truck."