Effect of PBT/PA6 Loading on the Flexural Properties of PP/PBT/PA6/EVA Blends

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Abstract: This study examines the flexural properties of blends containing polypropylene (PP), polybutylene terephthalate (PBT), polyamide 6 (PA6), and ethylene-vinyl acetate (EVA). Virgin polymers were used to investigate three formulations containing 4.8, 9.6, or 14.4 wt% of each engineering polymer, corresponding to combined PBT/PA6 contents of 9.6, 19.2, and 28.8 wt%, respectively. The PBT:PA6 mass ratio remained 1:1, and the EVA content was fixed at 4 wt% in these formulations. Injection-molded specimens were assessed by bending tests described with reference to ASTM D790, and five observations were reported for each formulation and the control. Mean reported flexural stress increased from 36.77 MPa for the control to 50.13 MPa for the formulation containing 14.4 wt% of each polymer. Mean reported strain increased from 7.32% to 12.41%. In contrast, flexural modulus reached its highest mean value, 1466.72 MPa, at 4.8 wt% of each polymer, compared with 1088.15 MPa for the control. Thus, the formulations with the highest reported stress and the highest initial stiffness were different. The results identify composition-dependent bending responses within the tested range, without establishing a universal optimum or a specific phase morphology. Because the reported strains exceed 5%, the test endpoints and compliance with ASTM D790 require clarification before the stress values can be treated as standard-compliant flexural strengths.

Keywords: polypropylene; PBT/PA6; ethylene-vinyl acetate; polymer blends; flexural properties

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1. Introduction

Plastic materials support a wide range of consumer and engineering applications, but their extensive use also creates challenges for waste collection, recovery, and reuse. Jambeck et al. estimated plastic waste inputs from land into the ocean, demonstrating the environmental importance of improving waste management rather than allowing discarded materials to enter marine environments [1]. This concern provides a broader motivation for investigating how polymer mixtures can retain useful mechanical properties. Toothbrush filaments and manufacturing trimmings are relevant examples of potential feedstocks containing engineering polymers such as polybutylene terephthalate (PBT) and polyamide 6 (PA6). However, converting such mixtures into useful products requires evidence about their processing behavior and performance, rather than an assumption that blending alone produces an effective recycled material.

Commercial reports describe the development of recycled-plastics markets [2], polyamide markets [3], and PBT markets [4]. Together, these sources provide industrial context for research on polymer reuse and blend formulation. Their forecasts concern different material categories, reporting periods, and market definitions, so they should not be interpreted as directly comparable measures of the performance or recyclability of a particular blend. The practical question addressed here is narrower: how does the combined loading of two engineering polymers affect the bending response of a PP-based formulation? Establishing this relationship with virgin materials can provide a controlled starting point for subsequent work with recovered feedstocks, whose composition and processing history may be less uniform.

The properties of a multicomponent blend depend on both the constituent polymers and the arrangement of its phases. Li et al. compared interfacial conductive networks in carbon-black-filled PA6/PBT blends and showed that blend composition and network structure influenced their electrical, rheological, and mechanical responses [5]. That study supports attention to phase organization when interpreting blend performance, but its carbon-black-containing systems differ from the PP/PBT/PA6/EVA formulations examined here. In particular, the morphology of one polymer system cannot be assigned to another solely because both contain PBT and PA6. Mechanical measurements must therefore be distinguished from proposed explanations involving dispersion, interfacial adhesion, or phase continuity.

Previous studies have examined several routes for modifying PBT/PA6-containing blends. Duong et al. investigated the influence of low-density polyethylene (LDPE) content on the impact strength of blends incorporating recycled PBT/PA6 from toothbrush filaments [6]. Their work connects polymer blending with a specific waste stream and emphasizes the importance of composition in determining the resulting response. Nga examined the mechanical properties of PBT/PA6 blends containing different proportions of polypropylene [7]. This work provides a direct precedent for considering PP as a major component of PBT/PA6-containing formulations, while also showing why separate mechanical properties should be evaluated rather than assuming that every property changes in the same direction.

Pham et al. studied the mechanical properties and microstructure of PBT/PA6/carbon-black blends at different carbon-black contents [8]. Their investigation further illustrates that adding a constituent does not necessarily produce a monotonic improvement across an entire formulation range. Taken together, these studies motivate a comparison that explicitly separates composition, the mechanical quantity being measured, and the conditions under which the measurement is obtained. They do not establish that the highest additive loading is always the most useful formulation, nor do they remove the need to examine variability among individual specimens.

PP is widely used because of its processing versatility and its range of physical and mechanical properties, as reviewed by Maddah [9]. Its response also depends on structural factors, including crystalline form; the study by Li et al. on the heat of fusion of beta-polypropylene is relevant to this distinction [10]. Nevertheless, crystallinity was not measured in the present work, and changes in bending response cannot be assigned quantitatively to crystallinity. Differences between PP and the polar engineering polymers also make interfacial behavior an important consideration. EVA was included at a constant loading in the three PBT/PA6-containing formulations, but its specific contribution must be distinguished from the effects of changing the other polymer contents.

Do et al. investigated melt-mixing and rheological behavior in EVA-based nanosilica composites containing maleic-anhydride-grafted EVA [11]. Their findings concern a chemically modified compatibilizer and a different dispersed phase; they do not directly demonstrate that unmodified EVA compatibilizes the present four-polymer blend. Consequently, EVA is treated here as a formulation component whose independent effect was not isolated. A controlled comparison with EVA-free formulations and direct observations of the interfaces would be needed to establish a compatibilization mechanism.

The present study examines the effect of increasing the combined PBT/PA6 loading while maintaining a PBT:PA6 mass ratio of 1:1 and an EVA content of 4 wt% in the three formulated blends. The research question is whether reported flexural stress, strain, and modulus follow the same composition-dependent trend. This distinction matters because resistance to bending deformation and the stress sustained at a reported test endpoint describe different aspects of performance. The study uses virgin polymers and therefore provides evidence about the stated formulations, rather than direct evidence of the properties of recycled toothbrush waste. Its objective is to identify the observed trade-offs within the tested range and to distinguish measured outcomes from mechanisms requiring further verification.

2. Experimental Methods

2.1. Materials and Blend Compositions

The four starting materials are identified in Figure 1. Virgin PP, grade PP-5704 PR, was manufactured by SABIC, Saudi Arabia, and supplied by Truong Thong Plastics Joint Stock Company. Virgin PBT, grade TC BN60, was supplied by Tacoma Company. Virgin PA6, grade N140, was identified as a LiBoLon material and supplied by MoSuCo Co., Ltd. Virgin EVA pellets, grade 7350F, were manufactured by SABIC and supplied by Phu Hoa An Plastics Joint Stock Company. The material designations are retained as reported; the precise manufacturer information for PA6 requires confirmation against the supplier documentation.



Figure 1. Materials: (a) PP, (b) PBT, (c) PA6, and (d) EVA

The blend compositions are listed in Table 1. Each row sums to 100 wt%. The specimen codes are retained as convenient identifiers, although their abbreviated numbers do not give the exact individual loadings. Specifically, 4PBT/4PA6 contains 4.8 wt% PBT and 4.8 wt% PA6; 9PBT/9PA6 contains 9.6 wt% of each; and 14PBT/14PA6 contains 14.4 wt% of each. Their combined PBT/PA6 contents are therefore 9.6, 19.2, and 28.8 wt%, respectively. Increasing this combined loading reduces the PP content while leaving EVA at 4 wt%. The PBT:PA6 ratio itself does not change. A control designated 0PBT/0PA6 is included in the results, but its complete PP/EVA composition was not specified in the supplied experimental description.

Table 1. Compositions of the PP/PBT/PA6/EVA Blends

Specimen	PP (wt.%)	PBT (wt.%)	PA6 (wt.%)	EVA (wt.%)
4PBT/4PA6	86.4	4.8	4.8	4
9PBT/9PA6	76.8	9.6	9.6	4
14PBT/14PA6	67.2	14.4	14.4	4

2.2. Specimen Preparation and Conditioning

The polymer blends were prepared by mixing and granulation according to the stated mass fractions before injection molding. The reported drying treatment was 60°C for 1 h. Injection molding used a reported temperature of 210°C, an injection pressure of 80–110 bar, and an injection time of 5–7 s. The injection-speed setting was 50–60% of the machine control scale; this percentage is not a physical velocity. The ejection stroke was 30 mm, and the cooling time was 15–18 s. These values describe the settings supplied for the experiment. Barrel-zone temperatures, actual melt temperature, mixing conditions, and the adequacy of drying for the particular grades remain necessary details for a fully reproducible processing description.

The specimens had nominal dimensions of 3.2 mm in thickness, 12.7 mm in width, and 127 mm in length. The stated conditioning conditions were 23 ± 2°C and 50 ± 5% relative humidity for at least 40 h. Because these conditions appeared in brackets in the source description, they require confirmation against the laboratory record. The three PBT/PA6-containing specimen groups are shown in Figure 2, with panels corresponding

to increasing combined loading. Consistent specimen preparation and conditioning are important for comparisons among these formulations, particularly because differences in specimen history could otherwise be mistaken for composition effects.

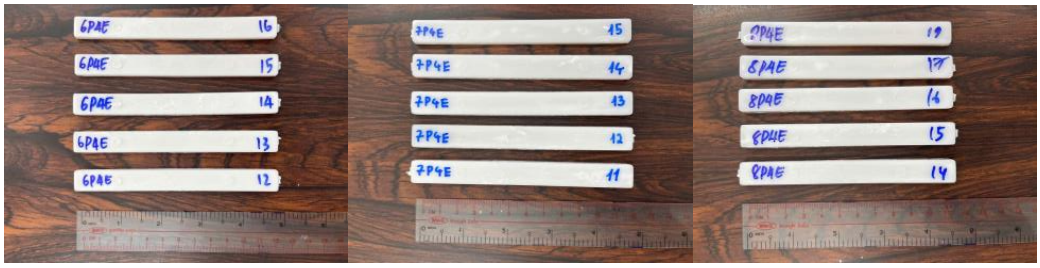


Figure 2. Blend Specimens: (a) 4PBT/4PA6, (b) 9PBT/9PA6, and (c) 14PBT/14PA6

2.3. Flexural Testing and Data Reporting

Bending tests were performed using a Shimadzu AG-X Plus universal testing machine with a stated capacity of 20 kN. The reported procedure comprised checking and adjusting the instrumentation, positioning the specimen in the fixture, starting the test, recording the response, and removing the tested specimen. ASTM D790 is the stated methodological reference [12]. However, the standard edition and procedure actually used, support span, crosshead rate, method of measuring deflection, and interval used to determine modulus were not provided. These details should be established before the measurements are presented as fully reproducible, standard-compliant flexural properties.

Five observations are reported for each group. Arithmetic means and sample standard deviations were recalculated from the displayed individual values, with the standard deviation using a denominator of four for each five-observation group. Results are rounded to two decimal places. Small differences from the original summaries arise from this recalculation; no individual measurement has been changed. Percentage comparisons in the discussion use the recalculated group means. The available results support descriptive comparisons, but no inferential significance test or independently replicated processing-batch analysis is reported.

The reported strain values require particular care. ASTM D790 limits the relevant comparison procedures to a maximum outer-fiber strain of 5%, whereas the listed strain observations exceed that value. The supplied description does not establish whether the stress values correspond to yield, fracture, a maximum reached within the permitted strain range, or a later endpoint. Accordingly, the values below are described as reported flexural stresses and strains. They are preserved for examination, but their interpretation as ASTM D790 flexural strengths requires the original load–deflection records and confirmation of the endpoint definitions. The standard reference is included to clarify this reporting issue, not to imply that its latest edition was necessarily used in the experiment.

3. Results and Discussion

3.1. Reported Flexural Stress

The stress–strain plots for the three PBT/PA6-containing formulations are presented in Figure 3. Their panel order corresponds to 4PBT/4PA6, 9PBT/9PA6, and 14PBT/14PA6. The group stress comparison is summarized in Figure 4, and the underlying individual values are listed in Table 2. The recalculated mean stress increases from 36.77 MPa for the control to 46.26 MPa for 4PBT/4PA6, 48.93 MPa for 9PBT/9PA6, and 50.13 MPa for 14PBT/14PA6. Thus, the group means increase monotonically with combined PBT/PA6 loading over the compositions examined.

The differences from the control are approximately 25.8%, 33.1%, and 36.3%, respectively. The increase between the two highest-loading groups is much smaller than the

increase between the control and the lowest-loading blend. This pattern suggests diminishing changes in the reported mean stress over the tested range, although it does not establish the response at untested compositions. The standard deviations are 1.96, 2.54, 0.71, and 1.75 MPa in the same group order. These values describe specimen-to-specimen variation in the supplied observations; the ordering of the means should not be described as statistically significant without an appropriate analysis and a clearly specified experimental design.

Altay et al. investigated the effects of mineral fillers on the thermal, mechanical, and rheological properties of PP [13]. Their work provides a useful comparison in principle because it also examines how a second constituent modifies PP-based material performance. However, mineral-filled PP and the present polymer blends differ in composition, phase behavior, and potentially processing and test conditions. A direct ranking based on isolated stress values would not establish relative material quality or interfacial compatibility. In the present dataset, increased reported stress is an observed composition association; attributing it to improved load transfer remains an interpretation that requires direct structural evidence and confirmation of the test endpoints.

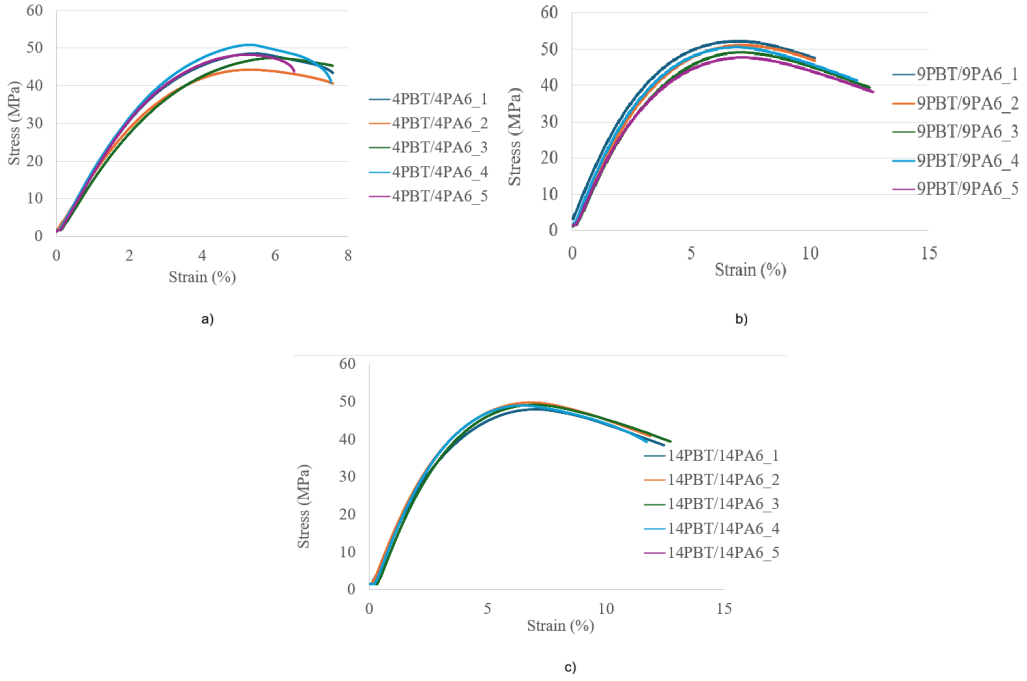


Figure 3. Flexural Stress–Strain Curves for the Three PBT/PA6-Containing Blends

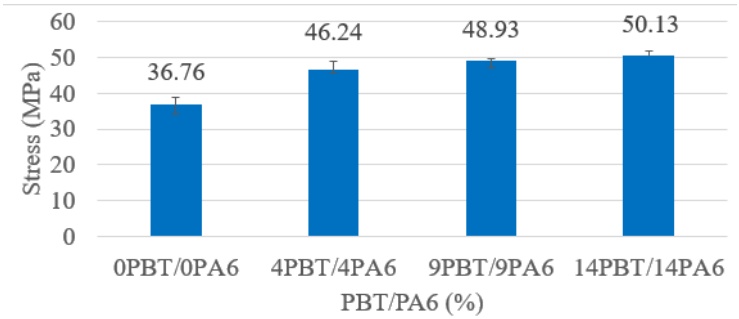


Figure 4. Average Reported Flexural Stress of the PP/PBT/PA6/EVA Blends

Table 2. Reported Flexural Stress of the PP/PBT/PA6/EVA Blends

Samples	Flexural Stress (MPa)			
	0PBT/0PA6	4PBT/4PA6	9PBT/9PA6	14PBT/14PA6
1	35.05	48.62	48.04	52.16
2	35.11	44.42	49.86	51.08
3	36.15	47.35	49.24	49.14
4	37.96	42.78	49.06	50.58
5	39.56	48.12	48.45	47.68
Average	36.77	46.26	48.93	50.13
Standard Deviation	1.96	2.54	0.71	1.75

3.2. Reported Flexural Strain

The strain comparison is presented in Figure 5, with individual observations and summary statistics in Table 3. Mean reported strain increases from 7.32% for the control to 9.21% for 4PBT/4PA6, 11.57% for 9PBT/9PA6, and 12.41% for 14PBT/14PA6. The corresponding sample standard deviations are 0.15, 2.01, 1.38, and 0.49 percentage points. The lowest-loading blend has the greatest spread in the reported strain observations, ranging from 6.65% to 11.83%, whereas the highest-loading blend ranges from 11.91% to 13.13%. Reporting these individual values makes the variation visible alongside the group averages.

The increasing strain values indicate greater reported deformation at the recorded endpoints, but the endpoint definition remains unresolved. They should not automatically be described as strain at fracture or permanent plastic deformation. Moreover, a larger strain value alone does not quantify toughness, which requires information about energy absorption over the loading history. The simultaneous increases in mean stress and strain therefore describe two measured trends rather than proof of a specific toughening mechanism.

A change in phase organization could influence deformation, but phase inversion and a co-continuous morphology were not established by the supplied measurements. No microscopy or other direct morphological characterization is reported for these specimens. Such mechanisms can be considered hypotheses for subsequent investigation, alongside differences in dispersion, crystallization, and interfacial response. The immediate reporting priority is to resolve the strain calculation and endpoint definitions because all listed strains lie above the 5% range relevant to the stated ASTM method. The original observations are retained rather than being truncated or converted into unsupported standard-compliant results.

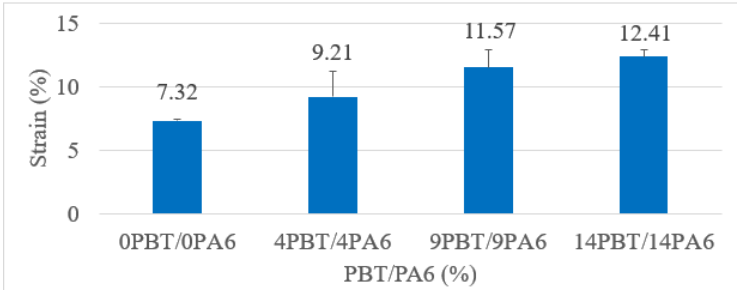


Figure 5. Average Reported Flexural Strain of the PP/PBT/PA6/EVA Blends

Table 3. Reported Flexural Strain of the PP/PBT/PA6/EVA Blends

Samples	Strain (%)			
	0PBT/0PA6	4PBT/4PA6	9PBT/9PA6	14PBT/14PA6
1	7.26	10.46	10.52	12.47
2	7.18	11.83	11.62	11.91
3	7.4	8.89	9.89	12.54
4	7.21	8.21	12.78	13.13
5	7.54	6.65	13.06	11.99
Average	7.32	9.21	11.57	12.41
Standard Deviation	0.15	2.01	1.38	0.49

3.3. Flexural Modulus and Formulation Trade-Offs

The modulus comparison is shown in Figure 6, and Table 4 reports the five observations for each group. The control has the lowest mean modulus, 1088.15 MPa. Adding 4.8 wt% of each engineering polymer gives the highest mean modulus, 1466.72 MPa. The mean then falls to 1302.11 MPa at 9.6 wt% of each polymer and rises to 1369.85 MPa at 14.4 wt% of each. All three formulated blends exceed the control mean, but modulus does not increase monotonically with combined PBT/PA6 loading. The corresponding increases relative to the control are approximately 34.8%, 19.7%, and 25.9%.

The sample standard deviations are 44.53, 161.96, 117.35, and 92.00 MPa, respectively. The lowest-loading blend combines the highest mean modulus with the largest absolute standard deviation. This variability should be considered when comparing formulations, especially because the present data do not establish between-batch reproducibility. The modulus values also depend on the slope-selection procedure and the measurement of specimen deflection, neither of which is fully described in the available method. Their calculation should therefore be checked against the original instrument records before drawing detailed conclusions about initial elastic behavior.

The different stress and modulus rankings are central to interpretation. The 14PBT/14PA6 formulation has the highest reported mean stress and strain, whereas 4PBT/4PA6 has the highest mean modulus. Consequently, selecting a blend for resistance to initial bending deformation may lead to a different choice from selecting one for the largest reported endpoint stress. The present results do not support describing one formulation as optimal for every engineering application. They instead identify a trade-off that should be evaluated against a specified service requirement after the measurement definitions have been confirmed.

Possible explanations include composition-dependent changes in phase dispersion, interfacial response, and crystalline structure. None was measured directly in this study, and the constant EVA loading prevents its independent contribution from being separated from the changing PP and PBT/PA6 fractions. The data therefore support a comparison of formulations as a whole. They do not establish that PBT and PA6 form a continuous reinforcing skeleton, that EVA produces strong interfacial bonding, or that the observed response will be reproduced with post-consumer feedstocks. These distinctions keep the interpretation aligned with the measurements actually available.

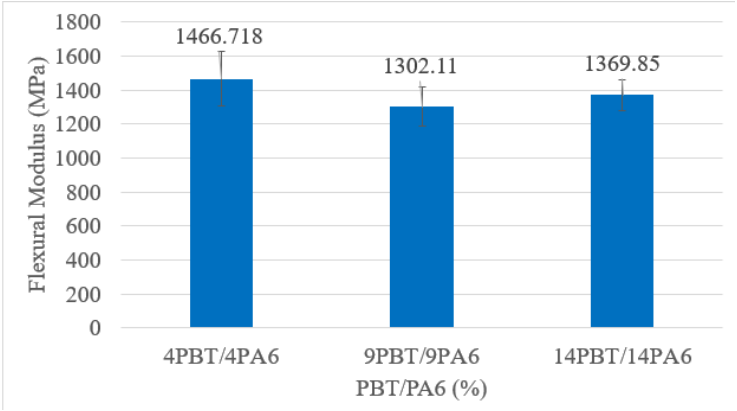


Figure 6. Average Flexural Modulus of the PP/PBT/PA6/EVA Blends

Table 4. Flexural Modulus of the PP/PBT/PA6/EVA Blends

Samples	Flexural Modulus (MPa)			
	0PBT/0PA6	4PBT/4PA6	9PBT/9PA6	14PBT/14PA6
1	1094.82	1621.76	1294.44	1470.53
2	1041.80	1447.64	1393.72	1407.63
3	1046.72	1416.60	1309.93	1311.05
4	1109.56	1231.02	1401.78	1418.50
5	1147.86	1616.57	1110.69	1241.53
Average	1088.15	1466.72	1302.11	1369.85
Standard Deviation	44.53	161.96	117.35	92.00

4. Conclusion

Increasing the combined PBT/PA6 content at a fixed 1:1 mass ratio and 4 wt% EVA produced different trends in the reported bending properties of the tested virgin-polymer blends. Mean reported stress rose from 36.77 MPa for the control to 50.13 MPa for 14PBT/14PA6, while mean reported strain rose from 7.32% to 12.41%. In contrast, mean modulus was highest for 4PBT/4PA6 at 1466.72 MPa, compared with 1088.15 MPa for the control. The research question is therefore answered by a distinction: reported stress and strain increased across the examined loadings, whereas modulus showed a non-monotonic response.

The highest-loading formulation is the leading candidate within this dataset when the criterion is reported endpoint stress, while the lowest-loading formulation has the highest mean initial stiffness. These findings do not establish a universal optimum, statistical significance, or a demonstrated compatibilization mechanism. Before the stress values are used as standard-compliant flexural strengths, the author must clarify the strain values exceeding 5%, the test endpoints, the control composition, and the missing fixture and loading parameters. The study provides a composition-dependent comparison of virgin-polymer formulations; applying its conclusions to recycled materials requires separate measurements on the intended recovered feedstock.

Competing Interests

The author declares no competing interests.

Data Availability

The individual measurements supporting the reported group comparisons are provided in Tables 2–4. The means and sample standard deviations can be reproduced from these tabulated observations. Original instrument records and additional processing details are not included in the supplied manuscript material.

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