**Rest Duration Tests Results**

- During the duration battery, the general characteristics of the tests demonstrated excellent repeatability.
- The time traces of the displacement input and force align well, and the shapes of the force traces, including bumps and waves, are nearly identical (Figure 2).
- In each plot, all 5 repetitions of the 2-hour interval tests are overlaid. As seen in the magnified force trace, on this scale even small deviations in the traces were repeatable between tests.
- There were, however, shifts in the magnitudes of these responses through the course of the series.

**Discussion**

The duration tests indicated incomplete viscoelastic recovery at every interval at 25°C. Within each duration group, the $F_{\text{norm}}$ value decreased with test repetition. Of particular interest are the implications of the nonsignificant duration-repetition interaction term; this indicates that each test repetition decreased $F_{\text{norm}}$ nearly the same amount, regardless of the rest duration between tests. A single linear regression indicates that each test reduces the $F_{\text{norm}}$ value of the subsequent test by 3.8 N throughout the entire test battery. While each decrement is small, over the course of the 40 tests in this battery, the amplitude of $F_{\text{norm}}$ decreased of 174 N. Furthermore, there was no evidence that an asymptote in this behavior was being approached, and the net effect of these inferences may increase with additional Repetitions.

This incomplete recovery introduced a systematic error, rather than a random error, which could create false positives or false negatives in the test results.

The gradual softening of the spine during the 25°C duration tests is at odds with the stiffening observed in the 12.5°C temperature tests. The cool temperature series also exhibited marked different creep behavior as compared to the duration tests (Figure 6).

At the cool 12.5°C temperature the total creep was almost twice as large at -2.11 mm when compared to the duration test battery. This data indicates that cooler temperatures increase the stiffness of the spine and increased peak loads. After exposure to higher loads, the creep recovery is diminished, leading to a shortened compliant height and higher strain levels. In this regime, softening due to incomplete stress relaxation is offset by the strain levels, leading to higher recorded forces.

The inconsistency in compressive loading shape as shown in the flattened areas in Figure 4 also presents an obstacle for experiments. In ATDs subjected to vertical loading (Goody et al., 1999), a similar flattened peak appears in the lumbar force trace for the curved Hybrid III spine. From the current study, there appears to be a buckling mode that is only observed under certain combinations of rate and temperature and that it is not predicted by a force or displacement threshold. With that unpredictability, peak force becomes a poor descriptor of the severity of the loading.

The temperature effects in the lumbar are very strong. While the stiffness of the Hill neck increased 115% at 0°C compared to near-room temperature (Schmidt et al., 2018), the lumbar saw the same stiffness increase at 12.5°C. To an even greater extent than the neck, the Hill lumbar spine’s characteristics require investigators to be cognizant of temperature as a confounding variable.

**Conclusions**

- No recovery period of 2 hours or less will allow complete viscoelastic recovery of the Hill lumbar spine under the weight of the dummy’s upper body at near-room temperature.
- Temperature effects were pronounced, resulting in compressive force differences of 261% over the range of 12.5°C to 37.5°C. Compared to the stiffness of the lumbar at 25°C, the stiffness at 37.5°C fell by 40% at 12.5°C, the stiffness more than doubled, increasing by 115%. The magnitude of these effects was rate-dependent.
- Only a modest decrease in temperature is necessary to dramatically change the response and repeatability of the lumbar in compressive loading. The large magnitude of the temperature effect has severe implications in its ability to overwhelm the contributions of targeted test variables.
- Care must be taken to control for the effects of temperature throughout testing, even in indoor laboratory environments. When reporting results from the Hill lumbar, the temperature near the spine-report.

**References**