Modeling 3D Ground Reaction Forces During Walking Using Nanocomposite Piezo-Responsive Foam Sensors

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3D ground reaction force (GRF) is an important characteristic of physical activity. Direct measurement of 3D GRF currently involves relatively immobile force plates, where only a small number of movement trials are typically recorded in a lab setting. Mobile measurement of 3D GRF would enable researchers to record these measures for more movement trials in an ecologically valid setting (i.e., outside the lab).
PURPOSE: To model 3D GRF during simulated walking from voltage responses of Nanocomposite Piezo-responsive Foam (NCPF) sensors. **METHODS:** NCPF sensors were placed in the heel, arch, ball, and toe of a shoe that was placed on a prosthetic foot. This shoe was then placed in a prosthetic testing apparatus (ISO 22675) and tested by a local manufacturer. 3D GRF, measured using a proprietary inline prosthetic load cell, and NCPF sensor responses were recorded for 111 simulated walking stance phases. 3D GRF and NCPF sensor data were filtered using 35- and 9-coefficient Fourier series, respectively. A MANOVA test evaluated the correlation of the NCPF and 3D GRF coefficients; then, all 35 3D GRF coefficients were modeled using the sensor coefficients that were significantly correlated ($\alpha = 0.005$). Next, prediction curves were constructed using coefficients from this regression model, the fit was analyzed using a cross-validation process, and prediction error for the model was reported and compared against the overall variability of the data. **RESULTS:** The regression model predicted 3D GRF with average error rates (i.e., average error of all predicted GRF data points, across all stance phases) that were significantly below the data variability rate: GRF_X (anterior-posterior), GRF_Y (medial-lateral) and GRF_Z (vertical) were predicted with 1.15%, 2.25%, and 1.34% average errors, respectively. An example figure for the sensor curve fit of GRF_Z is shown in Figure1. **CONCLUSION**: Using sensor coefficients to predict 3D GRF for simulated stable walking with a prosthetic foot results in a highly accurate model. NCPF sensors appear to be capable of gathering large amounts of ecologically valid GRF data during stable walking.
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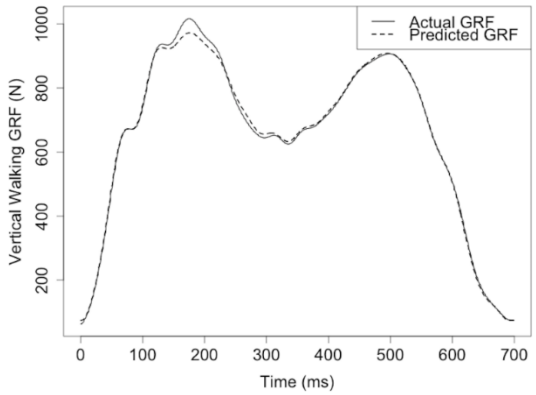

Figure 1. The predicted (using sensor coefficients) and measured GRF_Z, plotted against time for one randomly selected stance phase.