

EFFECTS OF EXPERIMENTAL SETUP AND MODELING ASSUMPTIONS ON PREDICTED TRUNK PROPERTIES USING A SYSTEM IDENTIFICATION METHOD

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INTRODUCTION

System identification methods have been used to estimate trunk mechanical properties (i.e., mass, stiffness, and damping) during sudden loading paradigms, as indirect measures of trunk neuromuscular control and to obtain information relevant to understanding and controlling low back pain. Despite an apparent sensitivity of these properties to several intrinsic and extrinsic factors, reported values have exhibited a wide range [1-3]. Such discrepancies may arise from sensitivities to experimental setup and modeling approaches. To address these issues, the present study investigated how trunk mechanical properties predicted with a system identification method are affected by: 1) positioning of the motion sensor; and 2) mechanical properties of elements between the trunk and the perturbing device (i.e., connecting rod, load cell, harness, and soft tissue below the harness).

METHODS

Six healthy individuals, gender balanced, with mean (SD) age of 23.2 (3.3) years and body mass of 69.3 (10.6) kg participated in the study. Participants stood in a custom metal frame designed to restrain pelvic and lower limb motions. A series of sudden, anteriorly-directed position perturbations were applied to the trunk at the T8 level via a rod-harness system. Each trial consisted of two 10-mm position perturbations at each of six different peak linear velocities (0.113, 0.232, 0.338, 0.457, 0.581, and 0.657 m/s). Displacements were measured at the motor and at the trunk surface. The former were obtained from a high-accuracy encoder (resolution ± 60 arcsec) attached to the servomotor shaft, while the latter were obtained from a high-accuracy (± 0.5 μm) laser displacement sensor (Keyence LK-G 150, Osaka, Japan) targeted at the midline of the dorsal aspect of the trunk immediately above the harness.

Driving forces were measured using a load cell (Interface SM2000, Scottsdale, AZ, USA) in-line with the connecting rod. Two dynamic models (Fig. 1) were used to estimate trunk mechanical properties in response to the perturbations: 1) a one degree-of-freedom (1-DOF) mass-spring-damper system representing only the trunk; and 2) a two degrees-of-freedom (2-DOF) system that also included an extra mass-spring-damper element simulating passive responses of the connecting elements.

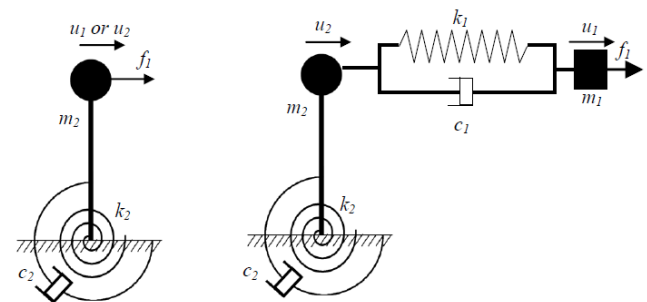


Figure 1. Schematic of the 1-DOF (left) and 2-DOF (right) models. u_1 : kinematics from motor encoder; u_2 : kinematics from laser sensor; f_1 : kinetics from load cell; m , k and c : mass, stiffness and damping of the trunk and connecting elements.

Model parameters were determined by minimizing squared errors in estimated trunk kinetics (model output) given measured kinematics (model input). To investigate the effects of motion sensor positioning on model predictions, parameters of the 1-DOF system were evaluated using either kinematics from the motor encoder as input (1-DOF-M) or those from the laser sensor (1-DOF-L).

RESULTS AND DISCUSSION

Laser sensor readings revealed that the trunk started moving anteriorly ~ 10 ms after initiation of motor movement, in part due to initial deformation of soft tissues and harness padding. As a result, soft tissue deformation was erroneously considered part of

trunk motion in the 1-DOF-M model. Accordingly, the least-square curve fitting for the 1-DOF-M model simulated the trunk as a more damped structure. The 1-DOF-M was also not able to correctly capture the mass difference between males and females (Table 1). In contrast, parameters from the 2-DOF and the 1-DOF-L models were comparable, and these characterized the trunk as having more mass and less damping.

Predicted trunk mass was higher with the 1-DOF-L vs. 2-DOF models, reflecting inclusion of connecting element masses into predicted trunk mass in the former (Table 1). Other differences in predicted trunk stiffness and damping may as well be due to lumping of the properties of the connecting elements into the trunk properties in the 1-DOF-L model. Nonetheless, differences were small, mainly due to the use of relatively rigid connecting elements that resulted in a predominant contribution of trunk dynamic responses versus connecting elements to the measured force. Trunk stiffness in the current scenario (i.e., relaxed, upright posture) was predicted to be zero or negligible using all three models (Table 1).

Table 1. Predicted trunk mass (m), damping (c), and stiffness (k). Results are mean (SD) values over all trials, perturbing velocities, and participants.

		m (kg)	c (Nms/rad)	k (Nm/rad)
2-DOF Trunk	M	20.7 (1.4)	49 (4)	0 (0)
	F	16.2 (1.0)	18 (1)	0 (0)
	All	18.5 (1.2)	34 (2)	0 (0)
1-DOF- L	M	22.5 (1.5)	45 (4)	14 (25)
	F	18.4 (1.0)	15 (1)	100 (25)
	All	20.5 (1.2)	30 (2)	57 (3)
1-DOF- M	M	1.4 (1.9)	86 (4)	0 (0)
	F	2.8 (1.7)	48 (4)	0 (0)
	All	2.1 (1.8)	67 (4)	0 (0)

When the connecting rod was in tension (i.e., when pulling the trunk anteriorly), all three models predicted forces from measured kinematics similar to those measured ($r > 0.98$; Fig. 2). However, only the 2-DOF model provided reasonable

representations of trunk kinetics when rod was under compression (i.e., when trunk motion is stopped). Reflexive muscle responses in the present study are likely to occur when the connecting rod is under compression, and are expected to unload the connecting rod slightly. As such, measured trunk kinematics should be less than model predictions that do not account for the reflexive component.

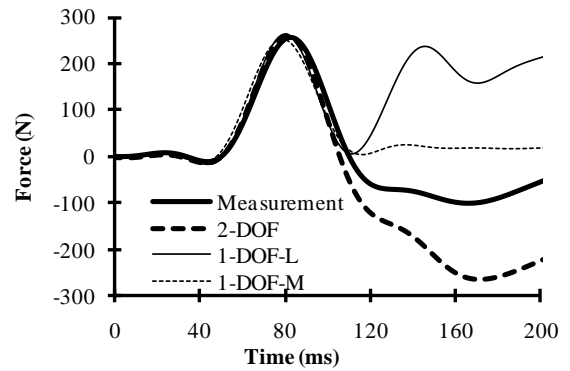


Figure 2. Sample predicted vs. measured forces during a trial with peak linear velocity = 0.338 m/s. Positive force = connecting rod in under tension.

CONCLUSIONS

The development of an effective method to assess trunk mechanical properties, as indirect measures of trunk neuromuscular control, may provide information relevant to the identification, control, and management of low back disorders. The results here suggest that more accurate estimates of trunk mechanical properties can be obtained by measuring kinematics at the trunk itself, and by modeling elements that connect the motor to the trunk.

REFERENCES

1. Granata KP and Rogers E. *J Electromyogr Kinesiol* **17**, 384-392, 2007.
2. Hodges P et al. *J Biomech* **42**, 61-66, 2009.
3. Gardner-Morse MG and Stokes IA. *J Biomech* **34**, 457-463, 2001.

ACKNOWLEDGEMENTS

This publication was supported by Cooperative Agreement Number R01-OH004089 from CDC-NIOSH. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of the CDC.