INTRODUCTION
In occupational and sport activities, sudden unexpected loads and movements occur that involve an elevated risk of spinal injury. The trunk response under sudden loading depends on latency period and reflex feedback that are affected by fatigue, disturbance anticipation, and existing coactivity. Pre-loads, training, and prior low-back pain. In sudden loading/unloading conditions, feedback reflexes contribute to trunk stiffness and stability but only after a delay of ~50 ms which adversely influences system control and stability. Both muscle intrinsic and reflexive stiffness values likely contribute to system stability during perturbations. Despite numerous measurement studies, no comprehensive modeling simulations have yet been attempted to evaluate the temporal variation of trunk muscle forces, internal spinal loads, and system stability prior and after sudden loading and unloading periods. Using the dynamic kinematics-driven approach coupled with a nonlinear finite element model of trunk active and passive systems, the primary objective of this study is to accurately predict trunk transient response under sudden loads. The model is employed to calculate the temporal variation of muscle forces, spinal loads, and stability prior and after a sudden release. In doing so, measured temporal variation of trunk rotation reported for one subject during ~200 ms before and after the release of a horizontal posterior force [1] is used as input into the model while accompanying EMG activities of agonist/antagonist muscles serve to validate model estimations. The trunk stability under this load condition is also studied.

METHODS
In the kinematics-driven approach, as compared with commonly-used single-level rigid link-segment models, kinematics data are prescribed into a nonlinear finite element model generating additional equations while accounting for nonlinear passive resistance and detailed musculoskeletal structure of the spine. The model is made of nonlinear beam elements representing the stiffness of T12-S1 motion segments and rigid elements representing lumbar vertebrae and thorax-neck-head assembly. For active musculature, 46 local (attached to lumbar vertebrae) and 10 global muscles are used on each side. To overcome the redundancy, at each time increment and spinal level, the sum of quadratic muscle stresses is minimized subject to upper/lower bounds on muscle forces. In addition to moment equilibrium equations, an additional equality equation on the balance of shear forces at the thorax is considered in order to avoid unfeasible large extension moments otherwise generated at lumbar levels. Reapplying the estimated muscle forces on the trunk, the iterative procedure continues till convergence is reached. To examine trunk stability, the critical muscle stiffness coefficient \( q \) to maintain stability is evaluated assuming a linear stiffness-force relation \( k = q \cdot f \) for muscles (L: muscle length) while using natural frequency and linear perturbation analyses at deformed configurations. In standing posture and based on measurements [1], the torso rotation is prescribed (Fig. 1) with the pelvis fixed and a posterior horizontal force of 300 N at the T9 level. A total upper body mass of 34 kg (i.e., 52% of mean mass of 65 kg) is distributed at different lever-arms along the spine. Additional studies are performed to evaluate the effects on trunk biodynamics of changes in position and magnitude of applied shear load.

RESULTS
Prior and shortly after release (time \( = 0 \)), the external oblique (EO) acts as the primary agonist muscle (Fig. 2). Upon sudden release, required moment at the T12 and hence EO force remain nearly constant during a delay period of ~60 ms after which time EO force diminishes while antagonist extensors, such as longissimus (LG), are recruited to control (i.e., stop and reverse) forward flexion. Activity in extensors disappears later as the trunk reverses its forward motion (Fig. 2). Relatively large compression forces are computed under these muscle forces (Fig. 3). Trunk stability deteriorates (i.e., critical \( q \) increases) only at the returning phase involving smaller extensor and abdominal muscle activities (Fig. 2). Perturbation loads applied at higher elevations and/or greater magnitudes increase trunk angular displacement, velocity, and acceleration in the latency period thus demanding greater antagonist muscle recruitment (and spinal loads) to restore the trunk position.

DISCUSSION
Predicted variations in recruitment of agonist and antagonist muscles as well as their post-release delay in activity agree very well with recorded data [1]. In the absence of any noticeable alteration in muscle activities during latency period after a sudden release, human trunk experiences a forward movement due to the imbalance thus generated between external and internal loads. The trunk dynamics after release is hence temporarily governed by agonist muscles, in particular EO, that were recruited before the release. Accordingly, subsequent reflexive and voluntary alterations in muscle activities act to limit and control trunk motion thereby altering this free trunk movement. It is found that a dynamic kinematics-driven approach utilizing the measured post-disturbance movements as input data is well-suited to estimate trunk response. Estimated muscle forces demonstrate basic response characteristics such as latency and reflex activation. The trunk is relatively stable before and after release which is due to activation in abdominal muscles in our sudden-release model; stability would deteriorate had, for example, a sudden loading been considered.

Excessive spinal loads due to large muscle forces in sudden loading conditions could be a considerable risk factor as the central nervous system has a tendency to overshoot while attempting to reflexively compensate for deviations between desired and actual kinematics, a situation that could deteriorate in presence of any abnormality or contamination in neural transmission. Current results offer great potential for improved design of workplace as well as training and rehabilitation programs.

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