

Paraspinal Muscle Vibration Alters Dynamic Motion of the Trunk

M. Arashanapalli
M.S.

S. E. Wilson¹
Ph.D.

e-mail: sewilson@ku.edu

Department of Mechanical Engineering,
University of Kansas,
Lawrence, KS 66045

Loss in dynamic stability of the low back has been identified as a potential factor in the etiology of low back injuries. A number of factors are important in the ability of a person to maintain an upright trunk posture including the preparatory stiffness of the trunk and the magnitude and timing of the neuromotor response. A neuromotor response requires appropriate sensing of joint motion. In this research, the role of this sensory ability in dynamic performance of the trunk was examined using a simple pendulum model of the trunk with neuromotor feedback. An increased sensory threshold was found to lead to increased torso flexion and increased delay in neuromotor response. This was confirmed experimentally using paraspinal muscle vibration which is known to alter proprioception of the muscle spindle organs. Before, during and after exposure to bilateral, paraspinal muscle vibration for 20 minutes, the dynamic response of subjects to an unexpected torso flexion load was examined. Subjects were found to have a 19.5% slower time to peak muscle activity and a 16.1% greater torso flexion during exposure to paraspinal muscle vibration. Torso flexion remained significantly increased after vibration exposure relative to before exposure. These results suggest that the neuromotor response plays an important role in trunk dynamics. Loss in sensitivity of the sensory system can have a detrimental effect on trunk dynamics, increasing delays in neuromotor response and increasing the motion of the trunk in response to an unexpected load. [DOI: 10.1115/1.2898734]

Keywords: lumbar spine, vibration, proprioception, stability

Introduction

Occupationally related low back disorders (LBDs) are a leading cause of worker disability affecting up to 47% of workers and costing society from \$25 to \$100 billion annually [1,2]. Loss of stability of the lumbar spine has been identified as a potential factor in the etiology of these injuries [3–7]. In particular, sudden loading events including slips and falls have been found to be associated with low back injuries in studies of injury rates in the industry [8,9]. Factors influencing spine stability such as reflex response time, lumbar cocontraction, and proprioception have been found to be altered in subjects with a history of low back pain [10–13].

A number of factors can contribute to the dynamic performance of the spine including the preparatory stiffening of the trunk through initial muscular activation and the timing and magnitude of neuromotor (reflex) response [3,14]. Neuromotor response has been shown to be delayed in subjects with a history of low back pain, in subjects with exposure to whole body vibration, and in subjects with muscular fatigue [11,15–17]. Delayed reflex response times have also been shown to be a risk factor for low back injury in athletes [6]. While a number of factors contribute to the dynamic motion of the spine, the neuromotor response has been shown to be necessary for dynamic performance of the trunk accounting for 42% of the total effective trunk stiffness [18].

A component of the neuromotor response is the ability to sense perturbations in joint position. Sensory systems in trunk dynamic stabilization include primarily the muscle spindle organs, but also ligament, intervertebral disk, and facet joint elements [19–22]. The muscle spindle organs are sensitive to local muscle vibration

making local muscle vibration a useful tool in evaluating the role of the muscle spindle organs. Such vibration induces increased errors in proprioceptive measures such as position sense and kinesthesia as well as a perception of muscle lengthening [23–26]. In addition to the kinesthetic illusions (perception of muscle lengthening) and increased error observed during muscle vibration, researchers have observed persistent proprioceptive errors after vibration exposure due possibly to neuromotor habituation or adaptation [27,28]. In the low back, researchers have demonstrated that vibration of the paraspinal muscles of the low back results in increased proprioceptive errors both during and after exposure to vibration [19,28]. Brumagne et al. [19], for example, found an increase in proprioceptive error from 2.16 deg before vibration to 4.51 deg during muscle vibration.

In this work, the objective was to examine the role of the sensory system in dynamic motion of the trunk both with a simple dynamic model and experimentally. Using the dynamic model, the effect of increasing sensory error (modeled as an increase in sensory threshold) on dynamic system performance of the trunk was assessed. The effects observed in the model were then tested experimentally by applying vibration to the paraspinal musculature and observing a subject's response to a sudden unexpected load applied to the trunk.

Model

To understand the role of the sensory system in trunk dynamic performance, a lumped parameter model of the trunk was created using SIMULINK (MATLAB, Natick, MA) and a variable step, Runge–Kutta differential equation solver. In this model, trunk dynamics were modeled as a second order, inverted pendulum system (Fig. 1) as follows:

$$I\ddot{\theta} + B\dot{\theta} + K\theta - mgl \sin \theta = M_p \quad (1)$$

where θ is the angle of trunk flexion, I is the rotation inertia of the head-arms-trunk (HAT), B is the damping constant, K is the

¹Corresponding author.

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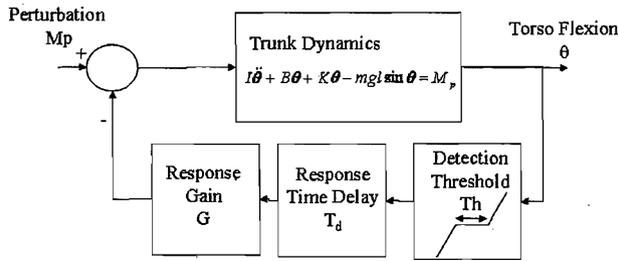
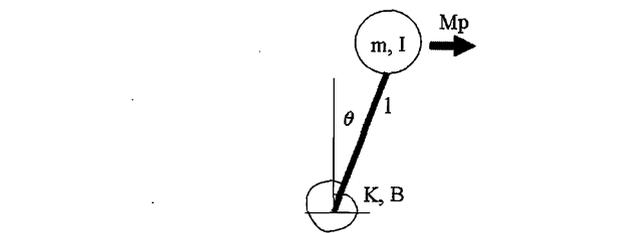


Fig. 1 The model on trunk dynamics in response to a sudden load consisted of an inverted pendulum model with a neuromotor response feedback. The neuromotor response was modulated by a neuromotor gain (G), a time delay (T_d), and a detection threshold (Th).

preparatory trunk stiffness, m is the HAT mass, l is the height of the center of mass, and M is a perturbation moment. Torso inertia and torso geometry were estimated using anthropometric data from Winter [29]. For this analysis, a 78 kg, 1.755 m male was used. The rotational inertia of the HAT (I) was estimated as 12.47 kg m², the HAT mass (m) as 52.9 kg, and the height of the center of mass (l) as 0.381 m. The damping constant (B) was calculated based on maintaining a damping ratio (ζ) of approximately 0.2 for the combined stiffness and neuromotor response gain as follows:

$$B = 2\zeta\sqrt{(K - mgl + G)I} \quad (2)$$

Similar simple models of trunk dynamics have been shown to be effective in modeling sudden loading dynamics in the trunk [16,30–32].

To this model, a neuromotor response to angular deflection was added (Fig. 1). This response contained three components. First, a proportional gain (G) in the response represented the moment generated as a response to a unit change in angular deflection. Second, a time delay (T_d) of 70 ms was included to account for conduction and electromechanical delays in the neuromotor systems. This corresponds to the average reflex latencies of 67–71 ms reported by Granata et al. [33]. Finally, a detection threshold (Th) was included to model the ability of the sensory system to detect an angular deflection.

Cholewicki et al. found trunk stiffnesses of 1253 ± 760 N m/rad (21.88 ± 13.26 N m/deg) [31]. This trunk stiffness is the effective stiffness of the trunk dynamic response system and would include both the preparatory trunk stiffness (K) as well as the gain (G) from the neuromotor response system. In a simple, proportional feedback system, the effective stiffness would be the sum of the preparatory stiffness (K) and the gain (G). To examine the relative roles of the preparatory trunk stiffness and the response gain on the effect of the detection threshold, the effective stiffness of 1253 N m/rad was split between the trunk stiffness and the response gain. The ratio of response gain to trunk stiffness was then increased from 0 (no neuromotor response) to 1 (equal contributions of neuromotor gain and trunk stiffness).

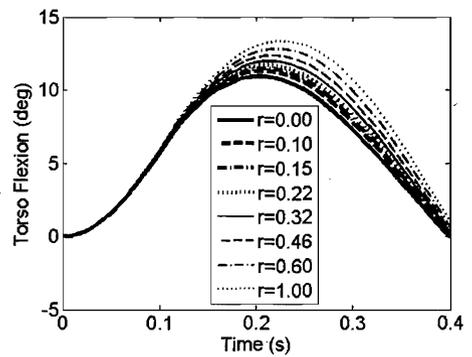


Fig. 2 Increasing the ratio of neuromotor gain over preparatory stiffness ($r = G/K$) resulted in an increase in TF and in time to peak TF. Although the effective overall trunk stiffness of a simple proportional feedback system should be the sum of neuromotor gain (G) plus intrinsic trunk stiffness (K , which was held constant), the time delay in the neuromotor gain led to a decrease in effective overall trunk stiffness and an increase in TF.

To simulate the experimental setup and the load cell pattern, a 115 N m perturbation moment was applied to the system for 0.10 s. The detection threshold was then varied from 0 deg to 5 deg. The detection threshold is the minimum angular deflection required before a neuromotor response is elicited. Increasing the detection threshold represents a loss in the ability to sense trunk posture. This range was selected to represent the increase in proprioceptive errors with local muscle vibration (from 2.16 deg to 4.51 deg) observed by Brumagne et al. [19].

Model Findings

Both increases in the ratio of response gain to preparatory stiffness and increases in the detection threshold were examined using the computational model. The ratio of response gain to preparatory stiffness represents the relative contribution of the neuromotor response versus the preparatory stiffness in the sudden loading dynamics. While some have argued the neuromotor response is not necessary in dynamic trunk dynamics response [34], others have found the neuromotor response to be important for trunk dynamics response [18]. By maintaining the sum of preparatory stiffness (K) and neuromotor response gain (G) at 1253 N m/rad, the overall effective stiffness of the system should remain relatively constant. However, due to the time delays in the neuromotor response, an increase in torso flexion and time to peak flexion is observed with increase in the ratio (Fig. 2). As the ratio increases, the neuromotor response gain increases which also results in an increased magnitude of the neuromotor response (Fig. 3).

From these results, two values of the ratio of gain to stiffness were selected for further analysis: $r = 0.1$, representing a system where the neuromotor response has very little effect and $r = 0.7$, representing a system with a strong neuromotor response component. The ratio of 0.7 corresponds to the neuromotor gain contributing 41% of the total effective stiffness, close to the 42% of the total effective trunk stiffness reported by Moorhouse [18]. The detection threshold was then varied from 0 deg to 5 deg. With the weak neuromotor response ($r = 0.1$), increasing the detection threshold was found to increase the time to initiation of the neuromotor response. However, the time to both peak neuromotor response and the magnitude of the peak torso flexion were unchanged (Figs. 4(a) and 5(a)). With a stronger neuromotor response ($r = 0.7$), increasing the detection threshold resulted in increases in the time to initiation of the neuromotor response, the time to peak neuromotor response, and the magnitude of the peak torso flexion (Figs. 4(b), 5(b), 6, and 7).

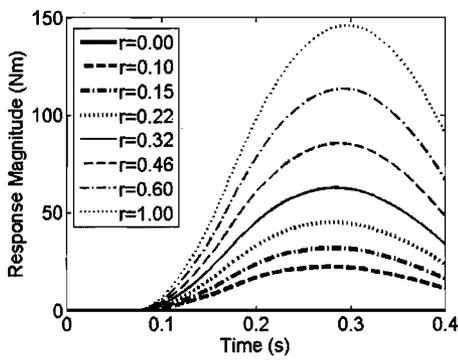


Fig. 3 Increasing the ratio of neuromotor gain over preparatory stiffness ($r=G/K$) increases the magnitude of the neuromotor response

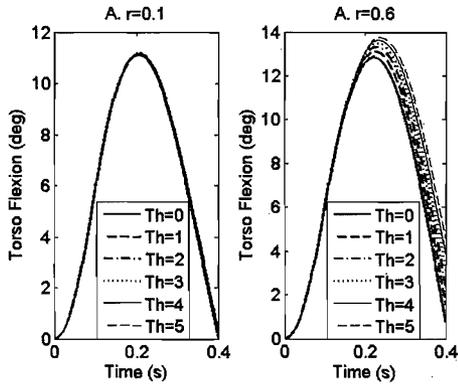


Fig. 4 Increasing the detection threshold of the neuromotor response (Th) was assessed at both a low neuromotor response (a) ($r=0.1$) and a high neuromotor response (b) ($r=0.7$). With a low neuromotor response, little change was observed in the TF. With a high neuromotor response, the magnitude of TF and the time to peak TF were increased with increases in the detection threshold.

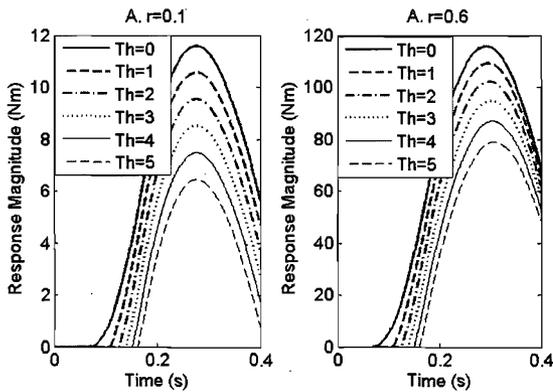


Fig. 5 Increasing the detection threshold of the neuromotor response (Th) was assessed at both a low neuromotor response ($r=0.1$) and a high neuromotor response ($r=0.7$). Increased delays in initiation of the response were observed at both response levels. An increased time to peak flexion was observed with a high neuromotor response. With the neuromotor response gain held constant, a decreased magnitude of the neuromotor response was observed.

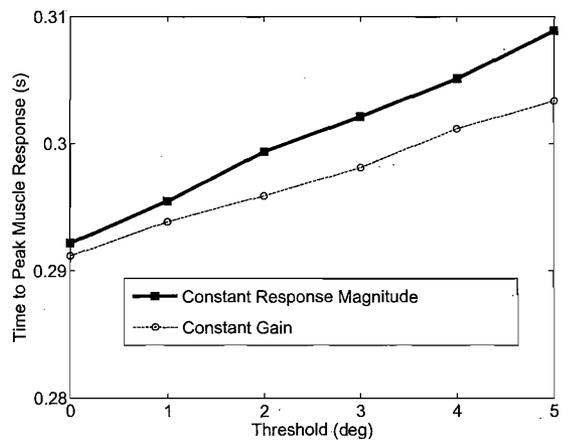


Fig. 6 Increasing the detection threshold of the neuromotor response (Th) was assessed both while maintaining a constant gain (as in Figs. 4 and 5) and while maintaining a constant response magnitude. With both, the time PM was found to increase with increases in the detection threshold. The ratio (r) of gain over stiffness for this analysis was maintained at 0.7.

With the strong neuromotor response, increasing the detection threshold, in conjunction with a constant, linear neuromotor gain, results in a decrease in magnitude of neuromotor response (Fig. 5). It could be argued that this decrease might be compensated by an increase in response gain. To investigate this possibility, while increasing the detection threshold, the gain was increased to maintain a constant magnitude of the neuromotor response. The time to peak neuromotor response and the magnitude of peak torso flexion were still found to increase with increasing detection threshold (Figs. 6 and 7).

These results suggest that if the neuromotor response is a factor in trunk dynamic response (r is large), altering the threshold of the sensory system should result in increased time to peak neuromotor response and increased peak torso flexion. Based on these results, it was hypothesized that paraspinal muscle vibration would result in increased time to peak neuromotor response and increased peak torso flexion.

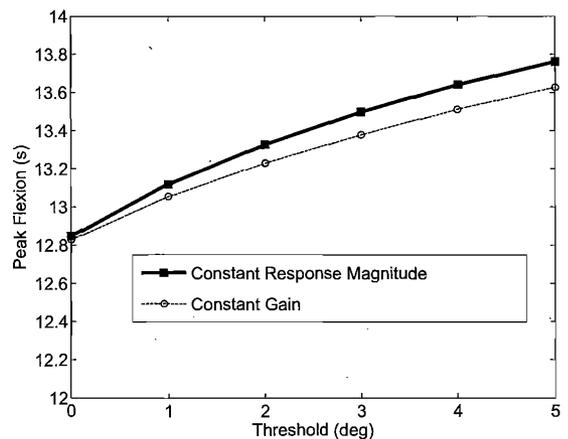


Fig. 7 Increasing the detection threshold of the neuromotor response (Th) was assessed both while maintaining a constant gain and while maintaining a constant response magnitude. With both, the TF was found to increase with increases in the detection threshold. The ratio (r) of gain over stiffness for this analysis was maintained at 0.7.

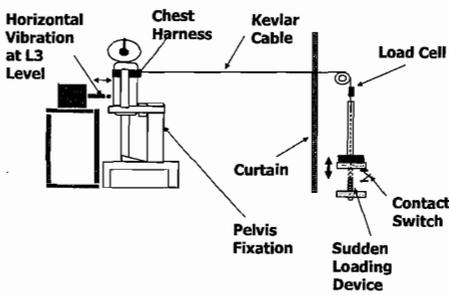


Fig. 8 In the experiment, the subject stood, pelvis fixed, with a chest harness attached to a sudden loading apparatus. Vibration was applied to the low back at the L3 level.

Experimental Methods

Twenty-one adult subjects (13 male and 8 female) with ages ranging from 21 to 33 years consented for this study, which was approved by the Human Subjects Committee, University of Kansas, Lawrence, KS. Subjects with low back pain for more than a week within the last year or with any other musculoskeletal disorder that would interfere in performing painless trunk flexion and extension were excluded from the study. In this experiment, the response to sudden loading was assessed in three conditions: before, during, and immediately after vibration exposure.

A constant amplitude (2 mm) vibration of 20 Hz frequency was applied bilaterally over the paraspinal muscle groups at the L3 level of the lumbar spine for 20 min via a mechanical vibrating device. In studies of vibration induced proprioceptive errors, frequencies ranging from 20 Hz to 120 Hz have been found to result altered proprioception [23,26,28]. In a pilot study of proprioceptive errors with paraspinal muscle vibration, 20 Hz was found to have the most pronounced effects on positioning errors both during and after muscle vibration [28].

A three-dimensional (3D) electromagnetic motion analysis system (Ascension Tech., Burlington, VT and Motion Monitor, Chicago, IL) was used to collect kinematic data. This system has a resolution of 0.08 cm and 0.1 deg and a rms accuracy of 0.76 cm and 0.5 deg. The three sensors were attached to the skin with a double-sided tape over the C7, T10, T12, and S1 spinous processes, and over the manubrium. Using the position of the T10 and S1 sensors, torso flexion angle was determined as the angle between a line connecting these sensors and vertical. The difference in angular orientation between the T10 and S1 sensors in the anterior-posterior plane was defined as the lumbar curvature. The manubrium marker allowed detection of trunk rotation and asymmetry of motion. This configuration is consistent with previous literature on lumbar position sense and lumbar-pelvic coordination [35,36]. The electromagnetic sensor data were collected at 40 Hz.

Surface electromyographic electrodes (Delsys, Boston, MA) were attached to the skin over the erector spinae muscle groups at the L2/L3 level of the spine with 4 cm interelectrode spacing. The electromyographic data (EMG) were collected at 1500 Hz. Raw EMG data were bandpass filtered between 20 Hz and 500 Hz with several notch filters (40 Hz, 60 Hz, 80 Hz, 120 Hz, 180 Hz, and 240 Hz) to remove electrical and electromagnetic noise. The EMG data were rectified and integrated using a 100-point Hanning window. Prior to the experiment, isometric, maximum, voluntary exertions were performed. The subjects were instructed to do extension exertions three times for 5 s against a fixed frame while standing with their pelvis fixed to a stationary support. The average of the integrated EMG (iEMG) for these maximal exertions was determined and used to normalize all subsequent iEMG.

During the sudden loading test, the subject stood with their hands to their sides, their legs straight, and their pelvis fixed in place by an anterior support and belt. The subject wore a chest harness to which a weight was attached by a Kevlar cable via a

load cell and a pulley (Fig. 8). Both audio and visual cues were eliminated using headphones with music and a curtain blocking the subject's view of the drop mechanism. A load cell recorded the tension in the cable (Transducer Techniques, Temecula, CA). A preload (0.5 kg) was applied to maintain tension in the cable. To create a sudden impulse load, a weight equal to 10% body weight was dropped at a height of 5 cm. This weight was allowed to bounce against springs attached to the weight holder to create an impulse load. A contact switch was used to indicate the instant the dropped weight made contact with the springs. The subject was instructed to match the target lumbar curvature and target torso flexion (to a visual biofeedback) prior to the sudden load to ensure the same preperturbation posture throughout the experiment.

During the sudden loading protocol, the electromyographic data, the load cell data, and the contact switch data were simultaneously collected at 1500 Hz for 5 s. Trunk motion was collected from the electromagnetic markers at 40 Hz simultaneously. The sudden loading protocol was repeated three times for each condition.

EMG data from the right side erector spinae muscle group were analyzed to find the time to peak muscular activity (timePM). This timePM was defined as the time between the onset of the contact switch and the peak muscular response measured by iEMG. The preparatory muscle activity (preEMG) was calculated as the average iEMG for the 750 ms prior to the onset of the contact switch. The peak muscular response (deltaEMG) was calculated as the difference between the maximum of the iEMG and the preEMG. The torso flexion (TF) resulting from the sudden perturbation was defined as the difference between the peak TF and the average of the TF 750 ms before the perturbation.

Huynh-Feldt adjusted, repeated measure analyses of variance (ANOVA) was performed with the timePM, peak muscular activity (deltaEMG), and the TF magnitude as dependent variables. The independent variables for these analyses were time (before, during, and after vibration) and trial number (first, second, or third repeat). Multiple comparisons of the significant effects were further analyzed with simple within-subject contrasts. These analyses were performed to test the hypotheses that timePM, deltaEMG, and TF would increase either during or after exposure to whole body vibration relative to before exposure. Additional repeated measure ANOVA was performed on the preEMG and preTF to ascertain if changes occurred in the presudden load state of the subject with vibration exposure. These measures were assessed to examine other potential factors in the dynamic performance of the low back.

Experimental Results

The computational model predicted that if neuromotor response was large, increases in the detection threshold (representing loss in sensitivity of the sensory system) would result in increased time to peak neuromotor response, decreased magnitude of neuromotor response, and increased TF magnitude. Experimentally, the time to peak neuromotor response can be observed by the time to peak erector spinae muscle activity (timePM). The timePM was found to increase from 213.4 (SD 57.0) ms to 255.0 ms (SD 62.9) during vibration and 237.4 (SD 70.6) ms after vibration (Table 1). A Huynh-Feldt adjusted, repeated measure ANOVA found the effect of the vibration condition to be significant ($p < 0.01$, Table 2). Further within-subject contrasts found significant increases in timePM between the before and during conditions ($p < 0.01$, Table 2), but only a trend between the before and after vibration conditions ($p = 0.09$, Table 2). The magnitude of the ES muscle activity (deltaEMG) was also found to increase from 41.5 (SD 48.1) %max to 46.8 (SD 59.5) %max during vibration and 49.0 (SD 52.5) %max after vibration (Table 1). However, this increase was not found to be statistically significant ($p = 0.22$, Table 2).

The TF magnitude was found to increase both during and after vibration relative to before vibration exposure (Table 1). The TF

Table 1 In the experiment, the sudden loading protocol was repeated three times before, during, and after vibration exposure. Time to peak muscle activity (timePM), peak muscular activity (deltaEMG), torso flexion (TF), preparatory muscular activity (preEMG), and preparatory torso flexion (preTF) were assessed.

	Before vibration		During vibration		After vibration	
	Mean	SD	Mean	SD	Mean	SD
timePM (ms)	213.4	57.0	255.0	62.9	237.4	70.6
deltaEMG (% max)	41.5	48.1	46.8	59.5	49.0	52.5
TF (deg)	8.77	3.39	10.18	5.19	9.38	3.70
preEMG (% max)	18.4	12.8	20.1	16.5	19.1	14.3
preTF (deg)	-0.37	3.51	-0.47	4.19	-0.59	2.90

increased from 8.77 (SD 3.39) deg to 10.18 (SD 5.19) deg during vibration and 9.38 (SD 3.70) deg after vibration. A Huynh-Feldt adjusted, repeated measure ANOVA found a significant effect of the vibration condition ($p < 0.05$, Table 2). Furthermore, within subjects contrasts revealed significance between the before and during vibration conditions ($p < 0.05$, Table 2) and the before and after conditions ($p < 0.05$, Table 2).

To assess if preparatory stiffness (K) behavior may have changed, the preEMG and preTF were also examined (Table 1). Neither the preparatory stiffness nor the preTF were found to change significantly with vibration condition ($p = 0.60$ and $p = 0.91$, Table 2).

Discussion

In the dynamic model of the trunk, increases in the sensory detection threshold (a model of increases in proprioceptive error) were predicted to result in increases in peak TF and time to peak neuromotor response (timePM). Experimentally, this was confirmed with increases in both TF and timePM during vibration and smaller increases in TF and timePM after vibration exposure relative to before vibration. For both TF and timePM, the increases observed during vibration were statistically significant. After vibration exposure, although there was a significant increase in TF relative to before vibration, only a trend ($p = 0.09$) was found of increase in the timePM. These increases in TF and timePM during vibration exposure confirm the model predictions. These results also suggest that the neuromotor response does play a role in the dynamic performance of the spine. If the neuromotor response was not a major component of the dynamic response, one would not expect to see changes in the TF with vibration.

In the model, the effect of an increasing threshold was assessed both while maintaining a constant, linear gain (G) and while maintaining a constant magnitude of neuromotor response. With a constant, linear gain, the magnitude of the neuromotor response would be expected to decrease with increasing detection threshold. Experimentally, the magnitude of the neuromotor response was found to increase slightly but not significantly. This suggests that rather than a constant, linear gain, a nonlinear or compensatory gain is a more appropriate model of the neuromotor response in this experiment.

In the experiment, preparatory values such as the preEMG and preTF were not found to change significantly with vibration. These preparatory values represent elements of the initial trunk stiffness (K). While a subject might increase the preEMG in order to stiffen the trunk and compensate for changes in the neuromotor response, such a compensation was not observed in this experiment.

While the model created for this study is anatomically simple, such models have proven successful in the past for modeling unexpected sudden loading and trunk dynamics [18,37,38]. Maintaining simplicity in the trunk model allows for a simpler representation of the neuromotor response. This neuromotor response

Table 2 Repeated measure ANOVA was performed for the five sudden loading variables. Multiple comparisons of the significant effects were made using within-subject contrasts to compare before vibration to both during and after vibration separately. Significant results ($p < 0.05$) are highlighted. (A) Time to peak muscle activity (timePM). (B) Peak muscular activity (deltaEMG). (C) Torso flexion (TF) magnitude. (D) Preparatory muscular activity (preEMG). (E) Preparatory torso flexion (preTF).

(A)	ANOVA	Epsilon	df	F	P
	Vibration	1.000	2.000	5.270	0.009
	Trial	1.000	2.000	0.816	0.449
	Vibration* Trial	1.000	4.000	0.402	0.807
	Within-subject contrasts	Levels		F	P
	Vibration	Before-during	10.400	0.004	
	Vibration	Before-after	3.168	0.090	
(B)	ANOVA	Epsilon	df	F	P
	Vibration	0.961	1.922	1.561	0.223
	Trial	1.000	2.000	0.165	0.849
	Vibration* Trial	0.350	1.400	0.769	0.430
(C)	ANOVA	Epsilon	df	F	P
	Vibration	0.673	1.346	4.251	0.038
	Trial	1.000	2.000	0.033	0.968
	Vibration* Trial	0.651	2.606	0.307	0.792
	Within-subject contrasts	Levels		F	P
	Vibration	Before-during	5.612	0.028	
	Vibration	Before-after	5.581	0.028	
(D)	ANOVA	Epsilon	df	F	P
	Vibration	1.000	2.000	0.515	0.601
	Trial	1.000	2.000	2.479	0.097
	Vibration* Trial	0.823	3.291	1.767	0.157
(E)	ANOVA	Epsilon	df	F	P
	Vibration	1.000	2.000	0.094	0.911
	Trial	0.704	1.408	0.703	0.456
	Vibration* Trial	0.435	1.739	1.976	0.159

can be seen as a composite of a number of possible reflex loops and sensory feedbacks. While it is impossible to identify specific neuromotor pathways with this model, the experimental results emphasize the role of muscle spindle organs of the paraspinal musculature in the sensory feedback.

This research demonstrates not only the role of the neuromotor system in dynamic response of the trunk and lumbar spine, but also the role of the paraspinal muscle spindle organs. The muscle spindle organs are generally thought to be primary proprioceptive elements in joints within the normal range of motion and loading [39,40]. In the spine, the paraspinal musculature is believed to be important in generating extension moments around the spine as well as in stabilizing the lumbar spine. This group of muscles would include a number of muscles including the erector spinae and multifidus muscles. Vibration applied to the paraspinal musculature should affect all of these muscles. Future work should examine the individual roles of these muscles. A number of other muscle groups may also contribute to low back stability including the rectus abdominus, the internal oblique, the external oblique, and the transversus abdominus muscles. These muscles may also contribute to proprioceptive sensing in the trunk and should also be investigated.

The effect of vibration on dynamic trunk motion is also intriguing. While this experiment focused on vibration applied locally to the paraspinal musculature, it may have implications for occupational vibration exposure such as whole body vibration in truck drivers. Whole body vibration has been documented as a risk factor for low back injuries in a number of occupations. The observed changes in dynamic performance of the spine in this experiment are similar to those observed in the whole body vibration by Wilder et al. and by Li and Wilson [15,17]. This suggests that vibration-induced effects in the muscle spindle organs may play a role in the mechanism of low back injuries. Future work should examine more closely the role proprioception may play in vibration-induced low back injuries.

Direct measurement of proprioception in the low back can be challenging as most of these measures have high variability [24,41–45]. In subjects with low back pain, these measurements can be confounded by the sensory feedback of pain. A number of studies have identified increased proprioceptive errors in subjects with a history of low back pain [24,44,45]. Other studies, however, have not observed these increases [41–43]. Studies examining sudden loading response times have observed increased delays in subjects with a history of low back pain [11,46]. Increases in time PM have also been identified as a predictor of low back injury [6]. If proprioceptive errors are indeed increased in subjects with a history of low back pain, the model presented here provides a possible reason why increases in neuromotor response delays are also observed in similar subjects. It also suggests a mechanism for injury, namely, that such increased errors lead to delayed responses and increased deflection in response to an unexpected load. Further research is necessary to demonstrate this potential link.

In conclusion, modeling of the dynamic response of the human torso to sudden loading suggests that changes in the sensory threshold for neuromotor response may have deleterious effects on dynamic trunk stability including increased delays in neuromotor response and increased TF in response to a sudden, unexpected perturbation. These changes were also observed experimentally by applying local vibration to the paraspinal musculature. These results indicate that the neuromotor response and, in particular, the muscle spindle organs of the paraspinal musculature play a role in maintaining trunk stability and in responding to unexpected perturbations.

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