

The Development of Response Strategies in Preparation for Sudden Loading to the Torso

S. A. Lavender, PhD,* W. S. Marras, PhD,† and R. A. Miller, PhD†

Sudden and unexpected loading to the torso has been reported in the literature as a potential cause of low-back disorders. When such loadings occur, it is hypothesized that the body's response is designed to minimize the destabilizing postural disturbance, and to minimize the mechanical loading of the musculoskeletal system. This study tested hypotheses regarding the role of task experience in the development of preparatory strategies that potentially minimize the postural disturbance to the body and minimize the mechanical loading of the spine. These strategies were hypothesized to consist of muscle pretensioning, postural changes, and intra-abdominal pressure (IAP). Four subjects participated in five to six experimental sessions in which a sudden load was applied by dropping a weight once a minute for 30 minutes. Electromyographic (EMG) data from 10 trunk muscles, IAP data, and postural data were collected during the initial session and final sessions for each subject. The results indicate where each subject developed a unique preparatory strategy. The preparation always involved the pretensioning of the erector spinae muscles, although the coactivation of the other trunk muscles was quite variable across subjects. During the sudden loading the overall postural disturbance was not consistently reduced; however, the trunk flexion was significantly reduced in most subjects. Furthermore, the estimated spinal compression due to muscle loading was significantly reduced in all subjects. (Key words: preparation, electromyography, EMG, sudden loading, lumbar spine, low-back injury)

neuromuscular system over-reacts, and in the process, damages tissue containing nociceptors.

A similar scenario can be expected to occur when a sudden load is imposed on the body. For example, a sudden load applied to the hands requires the rapid generation of muscular forces in the torso to prevent the postural disturbance from destabilizing the body to a point where a fall is possible. Such a scenario described 12.3% of accidental injuries described by Mitchell et al.²⁸ These results are consistent with research linking the frequency of sudden maximal efforts, especially when unexpected, to the occurrence of occupational low-back pain.¹⁹

A sudden response of the neuromuscular control system supporting the spine greatly increases the mechanical loading of the vertebral structures relative to comparable static loading. Two factors are responsible for this increased biomechanical load. First, sudden loading, by its nature, includes a dynamic component in the external force application. This requires that additional muscle force be generated to minimize the disturbance to the body's posture. Second, when the system is unexpectedly loaded, a startle response, where the system over-reacts, is generated.¹⁴ This response further accentuates the spinal loading created by the first component, thereby increasing the risk of low-back injury.

An individual's expectancies surrounding the temporal occurrence of a loading event significantly affects the magnitude of the startle response. For example, investigations studying sudden loading of the spine have reported strong relationships between warning time and muscle response.^{18,23} As warning time was increased from 0 to 400 milliseconds, the severity of the impulse load delivered to the spine decreased. It is theorized that the internal loadings were reduced through the formation of temporal expectancies as to when the sudden loading would occur. These expectancies are considered to drive a set of preparatory responses oriented toward minimizing the postural disturbance incurred during sudden loading situations. With regard to sudden loads transmitted to the lumbar region of the torso, these preparatory responses likely include muscle tensioning and coactivation, whole body postural changes, and the

Frequently combinations of lifting, bending, twisting, and general material handling tasks are described as the precursors of occupational back injuries.^{1,3,4,11} A recent survey of back injuries in an industrial setting determined that 66% of the first events associated with acute trauma injuries to the back involved some type of underfoot accident. Forty-six percent of these were slips without falls.²⁸ This suggests an injury scenario whereby the

From the *Department of Orthopedic Surgery, Rush-Presbyterian-St. Luke's Medical Center, Chicago, Illinois; and the †Department of Industrial and Systems Engineering, The Ohio State University, Columbus, Ohio.
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development of intra-abdominal pressure. In minimizing the postural disturbance, it is expected that the mechanical (compressive) loading on the spine also should be reduced.

Previous research has shown the sensitivity of preparatory muscle responses and anticipatory postural adjustments to the spatial expectations of an upcoming response. Several investigators have studied postural preparatory movements in response to voluntary or involuntary movements.^{6,7,25} Typically, the body's center of gravity (COG) is shifted so as to offset the resultant forces and moments generated in an upcoming movement.⁶

Similarly, Bouisset and Zattara⁵ have published electromyographic (EMG) results demonstrating the muscle activations in anticipation of a loading event. When subjected to sudden loading, subjects activated their muscles earlier when adequate warning time was available.¹⁷ This preparatory activation in the muscles can be considered a pretensioning response, analogous to preloading springs.¹⁵ In this manner the slack is removed from the system, giving the system a quicker and stiffer response.

Increased stiffness of the musculoskeletal response is often achieved through the coactivation of antagonistic muscles.¹⁶ The actual coactivation pattern employed has been shown to be a function of several factors. These include the rate of force development across a joint,¹² whether there is spatial or force level uncertainty regarding the required response,⁹ the magnitude of limb deceleration,²⁷ and the behavioral control strategy to unanticipated events.¹⁰ Furthermore, the cocontraction of antagonistic muscles is usually lessened as skilled behaviors develop.³² In the torso, several muscle groups potentially contribute to the stiffening of the lumbar intervertebral joints. These results make both the form and the magnitude of the muscular coactivation in the torso, while an individual prepares for a sudden loading, difficult to predict. Certainly task experience is a critical variable both from the standpoint of expectancy development as well as from the standpoint of motor control.

Preparation for sudden loading affecting the torso would potentially lead to increased intra-abdominal pressure (IAP). Research evaluating the influences of IAP on spinal loading has produced inconsistent results.² Generally, peaks in IAP have been observed early in the onset of torque development.⁸ Marras, Joynt, and King²⁴ further observed that discrepancies between IAP and torque onset occurred with increased trunk velocities. These authors have suggested the role of IAP may be that of a preparatory response whereby the trunk's acceleration is controlled. Therefore, under sudden loading conditions IAP is likely to be a component of the preparatory behavior. Under these conditions IAP is hypothesized to dampen the trunk acceleration due to the external loading. Overall, the literature is extremely

Table 1. Anthropometric Measures Taken From the Subjects

Measure	Subject		
	1	2	3
Age	41	44	23
Height	173.4	182.4	173.3
Weight	783.2	778.8	667.5
Elbow height	107.4	109.6	106.3
Lower arm length	45.1	51.5	45.6
Trunk breadth	31.0	27.7	28.0
Trunk depth	24.3	21.5	20.2

Lengths are given in centimeters and weights are given in Newtons.

limited regarding the development of biomechanical preparatory responses.

Furthermore, the modification of these responses as a function of task experience has not been investigated. The objective of this research was to test hypotheses regarding the changes in the preparatory response strategies, namely, the pretensioning of muscles, postural shifts, and the development of IAP, due to increased task experience. Specifically, the following hypotheses were tested with regard to increased task experience: 1) Muscle tensioning during preparation for a sudden loading would increase. 2) The preparatory coactivation of the antagonistic muscles (trunk flexors in this case) would increase. 3) The use of IAP before the loading would increase. 4) The preparatory posterior shift of the body's center of gravity would increase. 5) The postural disturbance during the sudden loading would be reduced. 6) The predicted spinal compressive forces during the sudden loading, as determined with an EMG-driven model, would also be reduced.

Methods

Approach. The current experiment used a variation of the sudden loading paradigm developed by Marras et al.²³ to study the preparatory responses. The advantage of this paradigm is that the onset of the loading is under the control of the experimenter. The experiment reported in this article used a periodic sudden loading event to facilitate the development of temporal expectancies through task experience. This assumed an individual monitors the passing of time and is capable of estimating the time until the next loading event. The literature has shown humans are capable of this task but are sensitive to the costs and benefits involved.³³

Subjects. Four subjects participated in the study. Men were used to minimize the likelihood of an exertion injury during the physically demanding protocol. All were between the ages of 23 and 44. Table 1 contains the subjects' anthropometric data. All subjects signed consent forms approved by the University Human Subjects Review Committee. Subjects were financially compensated for their efforts. Funding limitations allowed only four subjects.

Experimental Design. This research was designed to test hypotheses regarding the changes in preparatory responses elicited with increased task experience. Subjects received 53.4-N weights dropped at 1-minute intervals into a canvas bucket held in the hands. During each experimental session subjects received the weight 30 times over a 30-minute period. The primary independent variable in this experiment was the experience with the task. Each subject participated in five experimental sessions, with the exception of one subject. This subject was asked to participate in a sixth session because of an expected 2-day break during the first five sessions. Each subject served as their own control in that data collected in the sixth session was compared with the data collected during the first session. The dependent measures were classified into four sources:

1. Integrated electromyographic data (IEMG) from the 10 trunk muscles supporting the torso at the level of L5-S1 taken by the Schultz and Andersson³¹ transverse cutting plane technique. These muscles were the left and right latissimus dorsi (LATL and LATR), the left and right erector spinae (ERSR and ERSR), the left and right rectus abdominus (RABR and RABL), the left and right external oblique (EXOR and EXOL), and the left and right internal oblique (IOBR and IOBL).
2. Force plate data providing ground reaction forces. These are used to obtain the two-dimensional location of the body's COG.
3. Lumbar motion monitor data providing position data of the L5-S1 joint in the sagittal plane.
4. Intra-abdominal pressure (IAP) data.

Apparatus. Subjects stood in a three-sided booth-shaped structure shown in Figure 1. A 53.4-N weight, composed of a bag containing lead shot, was dropped through a stove pipe into a lightweight bucket (0.77 kg) held in the hands. The level of the force platform was adjusted for each subject such that the photocell on top of the bucket, held with the elbows at a right angle and wrists in a neutral posture, was approximately 32.5 cm below the stove pipe. The bucket was 27.3 cm deep, making the total vertical distance traveled by the weight 111.1 cm. The photocell, which marked when the weight entered the bucket, was activated approximately 60 milliseconds before the weight contacting the bottom of the bucket. Located 32.5 cm below the stove pipe, at a level equal to the top of the bucket, was a momentary pushbutton switch.

Five centimeters below the switch, a computer monitor displayed a compensatory tracking task. This task was designed to occupy the subjects' attention during the 1-minute period between loads. The task required subjects to keep a disk centered on the monitor's screen through the use of verbal directional commands. The position of the disk was determined by summing the verbal inputs and a driving function composed of five sine waves of varying amplitude and frequency. Beneath the monitor a wooden shelf allowed the subjects to rest the bucket in between weight drops.

A noise generator masked audio cues that could indicate when the weight would fall. Subjects also were given industrial hearing protective devices to further assure the removal of auditory cues.

The computer, operating with in-house software, sampled data channels from the A/D board at a rate of 100 Hz and with

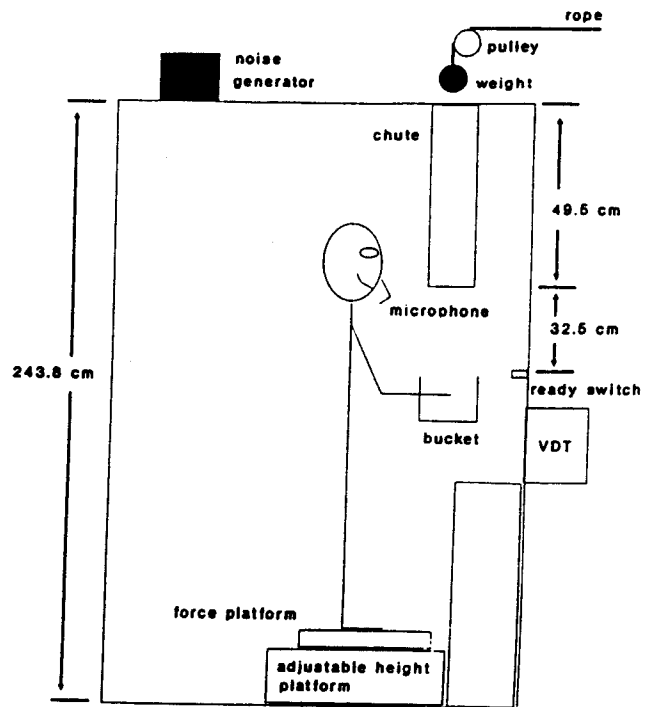


Figure 1. Diagram of experimental chamber in which subjects stood while participating in the study.

a 5 mV resolution. Analog data, as shown in Figure 2, were generated from five sources: the force platform, the EMG system, the IAP system, the lumbar motion monitor, and the event markers. Electromyographic data were collected using bipolar surface electrodes that were connected to preamplifiers attached to a belt worn by the subjects. The signals, passed via cable, were further amplified, rectified, integrated with a time constant of approximately 100 milliseconds, digitized, and stored in a personal computer.

Ground reaction forces used for obtaining the postural displacement data were collected using an Advanced Mechanical Technology Inc. (Newton, MA) OR6-5-1 series force platform. Intra-abdominal pressure data were collected by a Remote Control Systems Ltd. (London) telemetry unit. Because pressures sampled from different parts of the peritoneal cavity are similar,²⁹ the IAP capsule was inserted rectally. The transmitted radio signal was received by an antenna worn around the subject's waist. The pill, which was calibrated for each data collection session, was found to have a curvilinear relationship between pressure and the output voltage.

Postural data of the lumbar region were obtained with the Lumbar Motion Monitor (LMM), a device developed by the Biodynamics Laboratory at The Ohio State University, to measure the kinematics of the lumbar spine in each of the three planes of the body. The unit strapped over the spine by means of a premolded Orthoplast harness system. Instantaneous position data are obtained using in-house software that contained the calibration models for this device. This unit was used a measure of the postural disturbance in the torso due to sudden loading.

The final data sources were from event markers wired to provide an analogue pulse used in designating the onset of events in the data set. The events marked in this experiment were: 1) when the subject pushed the momentary switch, and

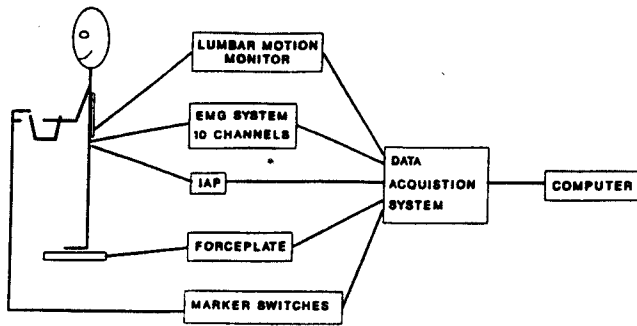


Figure 2. Data acquisition system used in collecting the 23 analog inputs.

2) when the weight broke the photobeam on its way into the bucket.

Procedure. Subjects received instructions that stressed the relative emphases on the two experimental tasks: receiving the periodically falling weights and the tracking task. Subjects were told that every minute a weight would fall. Their task was to allow the weight to drop into the bucket and hold for approximately 3 seconds. One minute after the presentation of the previous weight, another would be delivered. In between receiving weights the subjects were asked to perform the verbally controlled tracking task. Subjects were instructed to estimate when most of the 1-minute time interval had elapsed since the previous weight delivery. At this time they were asked to pause the secondary tracking task by saying "pause" into the microphone, to press the front of the bucket into the momentary switch, and to prepare to receive the falling weight. The momentary switch sent a pulse to the computer, indicating when the subject began preparing to receive the load. Subjects were not permitted to wear watches during the experimental sessions.

Muscles were isolated and the electrodes were applied to standard muscle sites as described by Marras.²² The electrode collars were circled with magic markers so similar pick-up sites could be used each day. After electrode placement the subjects were given the IAP pill to insert and sent to the lavatory. Subjects went through the same preparation before data collection on each day of the experiment. Data were saved on the first and final days of the experiment. On these days two isometric maximal voluntary contractions (MVCs), attempted trunk flexion, and trunk extension were performed while the subject was in an upright posture. These data were used in normalizing the EMG values along with resting EMG values, which were collected with the subjects standing in a relaxed posture.

After the EMG preparation and maximal exertions, subjects were fitted with the Lumbar Motion Monitor (LMM). Reference values were obtained by having the subject stand in an upright neutral posture.

After the setup procedures, the subject was asked to step into the experimental chamber. At this time the subject was given the hearing protective devices and the subject put on the microphone headset. The subject received a signal indicating when the first 1-minute interval started. The subject initiated the tracking task with a verbal command and for the next 30 minutes received the weight at 1-minute intervals.

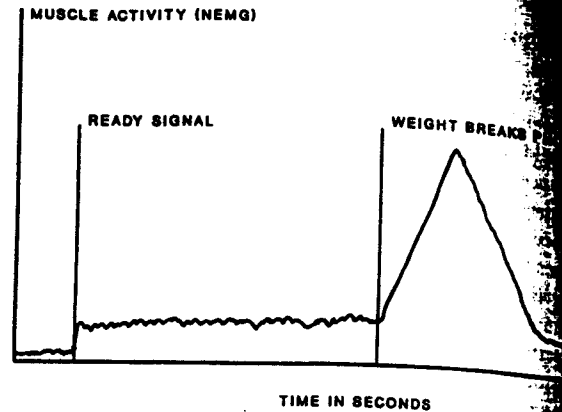


Figure 3. Example of data analysis for a single muscle. Plateau in the muscle response between the ready signal indicated the start of the preparatory period, and the break in the photobeam.

Data Treatment. Data were collected automatically by the computer once the testing session began. The computer sampled the data channels for 15 seconds, beginning 45 seconds into the 1-minute period. The sampling continued through the weight drop at 60 seconds into the period for an additional 15 seconds. The data were stored on the hard disk for analysis.

The EMG data were normalized for each subject. In the normalized signal computed in Equation 1 represents the difference between the observed value of the i^{th} muscle and its resting value divided by the total range of the EMG activity obtained from that muscle.

$$\text{NEMG}(i) = (\text{OBS}(i) - \text{REST}(i)) / (\text{MAX}(i) - \text{REST}(i))$$

Where:

OBS(i) = the current IEMG value of muscle i .

REST(i) = the minimum resting IEMG value of muscle i from the 5-second relaxed standing period.

MAX(i) = the maximum IEMG value from muscle i during the 5-second maximal voluntary contraction.

The data from the even-numbered trials were used in the current analysis. Therefore, from each session, 15 trials were potentially available for analysis. Because this study focused on preparatory responses, trials with less than a 2-second preparatory period, as defined by when the subject pushed the ready switch, were not included in the analysis. The normalized EMG (NEMG) data for each muscle sampled in the experiment looked similar to the schematic shown in Figure 3. Three phases of the NEMG response were observed in the time-varying signal. In the first phase, muscles were essentially at baseline levels until subjects pushed the momentary switch indicating they were ready to receive the weight. After the switch closure, subjects appeared to enter a second phase, a preparatory phase, in which the muscle forces were elevated before the loading. The third phase was initiated 60 milliseconds after the break in the photobeam that indicated when the weight contacted the bucket.

Normalized EMG data were used to estimate the internal torque contribution in the sagittal plane for each muscle. First, the preparatory NEMG were converted to muscle force as follows:

$$\text{Force}(i) = \text{NEMG}(i) * \text{XSECT}(i) * 50 \text{ N/cm}^2 \quad (2)$$

The muscle cross-sectional areas that were computed for each subject based on regression coefficients employing torso anthropometric data and constants provided in the literature.³⁰ The upper limit of 50 N/cm² for muscle tissue was used by McGill et al.²⁶ These muscle forces were then multiplied by their respective moment arms³⁰ and the trigonometric relations to obtain the muscle torques about the L5-S1 joint with respect to the axis parallel with the frontal and transverse planes.

The ground reaction forces and the COG displacement were obtained from the force platform. Only the COG displacements in the sagittal plane were used in this analysis.

The preparation data from the force platform and the lumbar motion monitor were sampled from the time at which the "ready" button was pressed to the point at which the load broke the photobeam. The COG displacement and lumbar position changes were computed by taking the difference between the final and initial values. During the drop phase, the change in these measures was defined as the difference between the final value of the preparatory phase and the most extreme point immediately after the weight contact.

Because of the small number of subjects and the individual differences observed in the preparatory responses, each subject's data was evaluated separately. Univariate analyses of variance (ANOVA) were conducted for each muscle, the IAP, and the postural measures within each subject to determine whether there were significant changes over the experimental sessions. Similarly, ANOVAs were conducted on the data collected after the sudden loading to compare whether these responses were changed because of the increased task experience.

■ Results

This section focuses on the changes in preparatory strategy changes due to the increase in task experience as seen in each of the four subjects. Furthermore, these preparatory strategies and the changes in these strategies are related to the measures obtained during the sudden loading.

Muscle Preparation

For the first subject, the torques generated by the muscles during the preparation period from the ten trunk muscles are shown in Figure 4A. In this subject's final session, although the muscle torques from the ERSR and the ERSL significantly changed with experience, the combined erector spinae torque was reduced by approximately 10% from the values observed in the initial session. This change, combined with a significant increase in the activation of the anterior musculature, served to increase the relative coactivation of the agonist and antagonist muscles.

Figure 4B shows the second subject, with increased task experience, to have developed a muscular preparation strategy employing low levels of erector spinae torque combined with high levels of torque from the external obliques. In creating this strategy, muscle torques in the initial session for both erector spinae significantly decreased while the muscle torques for both external oblique muscles significantly increased. Changes in the right rectus abdominis and the left internal oblique

were statistically significant; however, the magnitude of the contribution made by these muscles groups to the net stiffening of the L5-S1 joint was quite small. This subject could be characterized as developing a preparatory strategy whereby the torso is stabilized with a coactivation pattern consisting of torque production from the erector spinae and from the external oblique.

The third subject initially showed a strong coactivation pattern between the right erector spinae and left external oblique. As can be seen in Figure 4C, however, with increased task experience, the sizable torque contributed by the external obliques and the minimal torque contributed by the rectus abdominis all significantly decreased. The resulting preparatory strategy was dominated primarily by the ERSR.

The fourth subject's preparatory muscle responses resulted in torques generated by the left and right erector spinae, the rectus abdominis, the right internal oblique muscles (Figure 4D). Of these muscles, only the activation of the ERSL did not significantly change over the course of the experiment. Specifically, with more task experience, the ERSR and the IOBR were significantly increased while the RABR and the RABL were significantly decreased in their activities.

Preparatory IAP

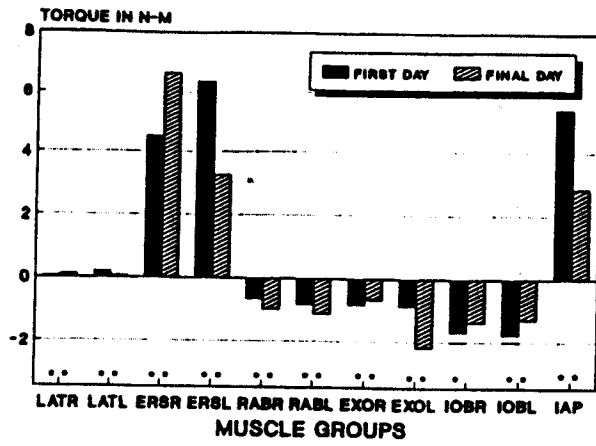
The use of IAP during the preparatory period was not observed in all subjects. Subject 1 decreased the extensor torque contribution from the IAP by 48% with increased task experience. Unfortunately, in Subject 2, the change in IAP could not be assessed because of the unavailability of this data from the subject's final day of testing. Both the third and the fourth subjects showed a negligible IAP response in both data collection sessions.

Preparatory COG Displacements and Lumbar Postural Changes

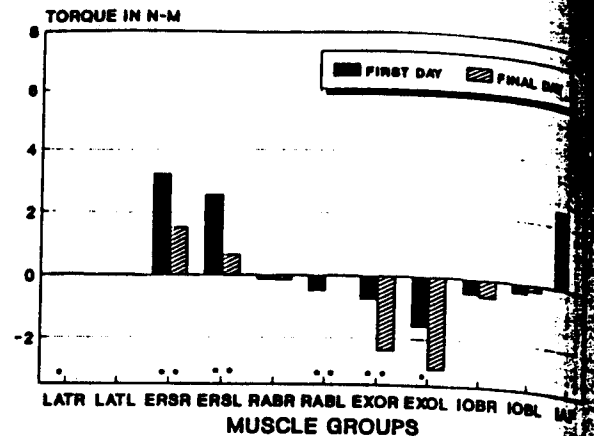
Measures of COG displacements and lumbar postural changes were obtained from the force platform and the LMM, respectively. Subjects 1, 2, and 4 showed no COG or lumbar displacement of any significance during the preparatory period. Subject 3 did initially shift his COG away from the loading. With increased task experience, however, this behavior was discontinued ($F = 4.58$, $df = 1,26$, $P < 0.05$). In both the initial and final experimental sessions, Subject 3 did show between 2.5 and 3° of lumbar extension before the loading. The disappearance of the COG displacement during the final session suggests the subject started bending his knees, thereby bringing the body's COG back to the original position. Likewise, the anterior muscle response seen in this subject's initial session, as perhaps a means to accommodate the COG shift, was discontinued with task experience.

Sudden Loading Results

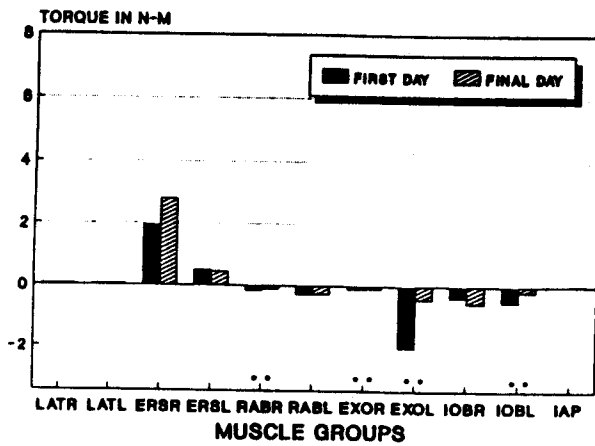
The development of preparatory strategies were hypothesized to minimize the postural disturbance during the sudden loading. With increased task experience, only one



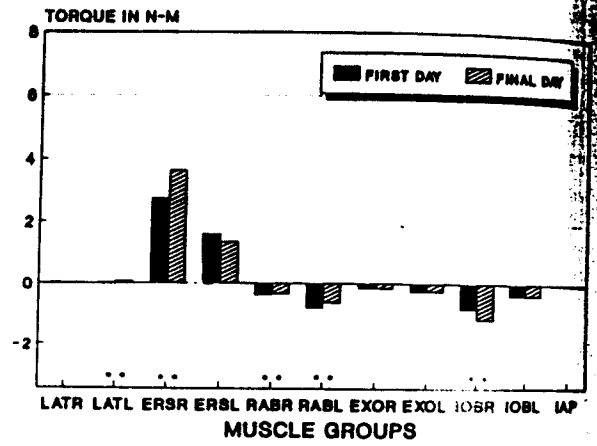
4a) Subject 1



4b) Subject 2



4c) Subject 3



4d) Subject 4

Figure 4. Preparatory muscle torques for Subjects 1-4 (4a-4d, respectively). Statistically significant differences are indicated with a "*" ($P < 0.01$) or a "****" ($P < 0.001$).

subject decreased his body's COG displacement during the loading (Figure 5). Subjects 1, 3, and 4, however, all displayed less of a disturbance in trunk posture in response to the sudden loading ($P < 0.001$ in all cases). Figure 6 shows the trunk flexion during the loading was reduced by 40, 26, and 47%, respectively. The second subject showed no significant changes in his torso flexion. The whole-body COG data provide information with regards to the trade-off between the use of lumbar flexion and hip flexion during the sudden loading. For example, Subjects 1 and 4 while showing decreased trunk flexion maintained a constant level of COG displacement. This suggests the lumbar flexion was replaced with hip flexion in these subjects as task experience increased.

The Marras and Sommerich model²¹ was used to calculate the compressive forces acting on the spine due to muscle activations. From Figure 7 it is apparent that all subjects reduced the compressive loading on the spine during the sudden loading. The range of these statistically significant decreases ($P < 0.01$) was between 12% and 29%.

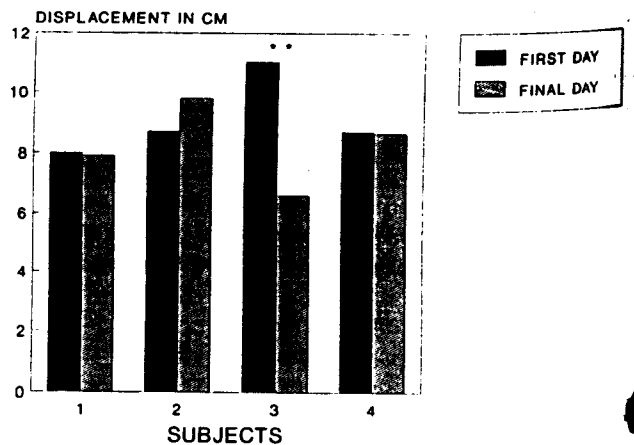


Figure 5. Peak forward COG displacement during the sudden loading for each subject as a function of the experimental session. Statistically significant differences are indicated with a "*" ($P < 0.01$) or a "****" ($P < 0.001$).

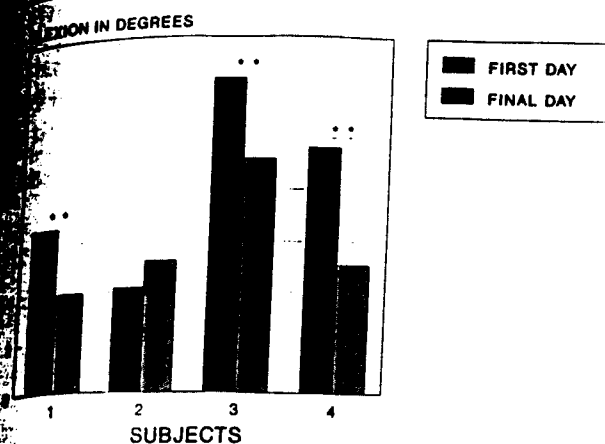


Figure 6. Sagittal lumbar flexion during sudden loading for each subject as a function of the experimental session. Statistically significant differences are indicated with a "*" ($P < 0.01$) or a "**" ($P < 0.001$).

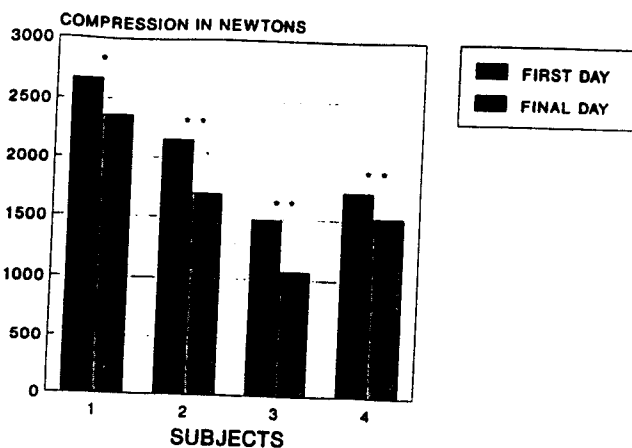


Figure 7. Peak compression values for each subject computed with the Marras and Sommerich model (1991) as a function of the experimental session. Statistically significant differences are indicated with a "*" ($P < 0.01$) or a "**" ($P < 0.001$).

Discussion

The results of this investigation demonstrate the role of task experience in allowing each subject to develop an adaptive preparatory response strategy for handling the periodic sudden loading. Although there were individual differences with regard to the strategy employed, most subjects developed strategies through repeated exposure to the experimental task that were successful in decreasing the destabilization of the torso. In addition, all subjects developed strategies that reduced the muscle forces compressing the spine during the loading. Across subjects there were distinct qualitative differences as to the preparatory strategy employed, however. These differences, in addition to the changes within each subject, will be discussed along with possible factors accounting for this variability.

Subjects were presented with a sudden loading at 1-minute intervals. Across experimental sessions, subjects improved their ability to estimate approximately when the weight would fall, thereby missing fewer of the falling weights. More importantly, subjects reliably prepared for the loading before the event itself. The emergence of a steady state during the preparatory phase, with regard to the development of muscle forces, was an unanticipated result. Data from operant conditioning studies using avoidance paradigms typically show increased response rates near the end of fixed time interval.¹³ A similar trend, for example, a monotonic increase in muscle force, was anticipated as subjects neared the onset of the sudden loading. Instead, subjects went into a ready state in which muscle forces were elevated, but essentially constant. Subjects remained in this state until the loading occurred.

The emergence of a preparatory state during the first session indicates how quickly we begin to develop expectancies and adapt our internal responses to biomechanically stressful situations. In fact, the muscle re-

sponses observed during the preparatory periods in the initial session were considerably above resting values. All subjects were observed to pretense their muscles¹⁵ in preparation for the sudden loading. The muscular preparatory strategy, which differed across subjects, can be described by two parameters, the total muscular torque (TMT) and the proportion of anterior muscle activation (AMA). The TMT gives the overall intensity of the muscular preparation while the AMA describes the relative coactivation of the anterior musculature. Because the sudden loading biomechanically works in opposition to the posterior muscles, the anterior muscles are considered to be the muscles that are "coactivated." Under these circumstances, the anterior muscles are considered to control the torso motion by resulting in increased posterior muscle activation and a stiffened lumbar spine. Table 2 shows the TMT for each subject across experimental sessions as well as the AMA for each subject. Although differing in their initial torque values, Subjects 1, 2, and 3 initially had very similar coactivation as determined by their AMA. Even during the final session, 3 of the 4 subjects showed AMA values clustered between 32% and 43%. The sensitivity of these coactivation indices in terms of stiffening and stabilizing the torso, still needs to be determined, however.

The use of postural changes to offset the subjects' center of gravity away from the loading were essentially nonexistent in the final data collection session. Only the third subject showed a rearward COG displacement during any of the sessions. Although this was discontinued with more task experience, this subject did continue to extend his torso away from the loading in the final session. The absence of this preparatory response, which has been described in the literature,⁶ is best explained by the nature of the experimental task. Subjects were required to keep the bucket directly under the chute through which the weight would drop.

Table 2. Total Muscular Torque (TMT) in Newton-Meters and the Anterior Muscle Activations (AMA) as Function of Experimental Session, Initial or Final

Subject	TMT		AMA	
	Initial	Final	Initial	Final
1	17.81	17.73	0.37	0.43
2	9.55	8.46	0.38	0.73
3	6.03	4.94	0.58	0.32
4	7.25	8.05	0.39	0.36

The AMA is defined as the ratio of the anterior muscle torque to the total muscle torque.

Therefore, any rearward shift in the torso or the whole body must be accompanied by an increased extension of the upper extremities. Such a strategy would have two adverse effects. First, any further extension of the arms would increase the external moment generated by the falling weight on the lumbar spine. And second, the shoulder complex would now be under increased stress.

The third preparatory response hypothesized to be active under these sudden loading conditions was IAP. Recordings in two of the four subjects showed IAP was not even a measurable quantity. And although two subjects showed moderate high torque values from their IAP in the initial session, data are only available from one of these subjects during the final experimental session. This one subject did continue to develop moderate extension torque with IAP during this final session. In general, however, the IAP data from the current experiment do not appear to support hypotheses that suggest that IAP functions as a preparatory mechanism.

These preparatory response strategies were hypothesized to aid in minimizing the postural disturbance and in reducing the spinal loading during the periodic sudden loading. Although little change was seen in most subjects with regard to whole body displacement, the postural disturbance to the lumbar region was generally reduced with increased task experience. Table 3 gives the mean torso flexion values for both sessions and the ratio of the final to the initial session. Averaging across the four subjects, the torso flexion during the final session was 78% of the initial value. The one subject showing a small increase in trunk flexion showed only minimal flexion during the initial session. Changes in the computed peak compression values indicate that all preparation strategies were successful in reducing the loads transmitted to the spine during the sudden loading. Looking across subjects, the compression in the final session was between 71% and 88% of that computed during the initial session, with a mean value of 82% (Table 4). Both of these quantities indicate that sudden loading was better handled by the subjects with increased task experience.

The variation in operating modes could be attributed to several factors. Anthropometric factors, such as differences in body mass, lower arm length, and trunk

Table 3. Lumbar Flexion During the Sudden Loading Degrees Between the Initial and Final Data Collection Sessions and the Ratio of the Final Session to the Initial Session Values for Each Subject

Subject	Experimental Session		Ratio of Final to Initial
	Initial	Final	
1	6.59	3.96	0.60
2	4.17	5.21	1.25
3	12.40	9.15	0.74
4	9.64	5.09	0.53
Mean	8.20	5.85	0.71
SD	3.58	2.27	0.32

Table 4. Peak Compression Values in Newtons During the Sudden Loading Computed Using the Marras and Sommerich (1991) Model

Subject	Experimental Session		Ratio of Final to Initial
	Initial	Final	
1	2674	2356	0.88
2	2159	1704	0.79
3	1494	1066	0.71
4	1742	1526	0.88
Mean	2017	1663	0.82
SD	517	535	0.08

Data from each subject for each of the data collection sessions as well as the ratio of the final session to the initial session (F/I) are presented.

dimensions could be expected to account for some of the variability seen across subjects. For example, the differences in muscle torques is partially a function of the torso dimensions as these were used to predict the moment arm lengths. Handedness was considered as a potential explanation for the asymmetry observed in some of the muscular preparatory strategies. This sample, even while quite small, did not support this explanation.

In summary, it should be noted that each subject developed a preparatory response strategy that allowed them to better cope with the sudden loading. Unlike previous research in this area, the current work has demonstrated the role of experience in the development of expectations and preparatory response strategies. Based on this experience, the subjects were able to develop behavioral strategies that protected them from the apparent hazards of the task. Likewise in industrial tasks, experienced employees will have developed their own behavior strategies for coping with their own workplace hazards. Training procedures aimed at increasing the learning rate for the safer response strategies would likely prove unsuccessful because of the variability in strategies observed even in this simple task. Training that focuses on the information necessary to develop adequate preparatory response strategies could prove beneficial. Additional research is needed, however, to

examine the effectiveness of such training. In sum, the use of engineering controls, where the workplace is restructured to reduce the likelihood of sudden loadings, should be stressed.

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Address reprint requests to

Steve Lavender, PhD
 Department of Orthopedic Surgery
 Rush-St. Luke's Medical Center
 1653 West Congress Parkway
 Chicago, IL 60612