SPINE Volume 27, Number 23, pp 2645–2653
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The Impact of Mental Processing and Pacing on Spine Loading

2002 Volvo Award in Biomechanics

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Study Design. The impact of various levels of mental processing and pacing (during lifting) on spine loading was monitored under laboratory conditions.

Objectives. To explore how mental demands and pacing influence the biomechanical response and subsequent spine loading and, to determine whether individual characteristics have a modifying role in the responses.

Summary of Background Data. Modern work often requires rapid physical exertions along with demands of mental processing (both psychosocial stressors). While the effect of physical workplace factors on spine loading has been widely documented, few studies have investigated the impact that interaction of psychosocial factors and individual factors has on spine loads.

Methods. For this study, 60 subjects lifted boxes while completing two types of mental processing tasks: 1) series tasks with decisions occurring before the act of lifting, and 2) simultaneous tasks with decisions occurring concurrently with the lift. For both of these mental processing conditions, two intensities of mental load were evaluated: simple and complex. Task pacing was also adjusted under slow and fast conditions. Finally, individual characteristics (personality and gender) were evaluated as potential modifiers. An electromyographically assisted model evaluated the three-dimensional spine loads under the experimental conditions.

Results. Simultaneous mental processing had the largest impact on the spine loads, with the complex intensity resulting in increases of 160 N with lateral shear, 80 N with anteroposterior shear, and 700 N with compression. Increased task pace produced greater lateral shear (by 20 N), anteroposterior shear (by 60 N), and compression loads (by 410 N). Gender and personality also influenced loadings by as much as 17%.

Conclusions. Mental processing stress acted as a catalyst for the biomechanical responses, leading to intensified spine loading. Mental stress appeared to occur as a function of time pressures on task performance and resulted in less controlled movements and increases in trunk muscle coactivation. These adjustments significantly increased spine loading. These results suggest a potential mechanism for the increase in low back pain risk resulting from psychosocial stress caused by modern work demands. [Key words: psychosocial, biomechanics, lifting, mental concentration] **Spine 2002;27:2645–2653**

The impact of low back pain (LBP) has been widely recognized as a burden on society, both financially and physically.[29,45,111] At some time during their lives, the majority of the working population (>80%) experience LBP,[45,111] with a yearly prevalence of 17.6%.[43] Prevalence of LBP is greater for individuals who work in physically demanding jobs. For these workers, it is the leading cause of disability (up to 47% of the workers affected).[9] However, our understanding of how work-related factors interact to result in LBP is poorly understood.

Epidemiologic studies have traditionally reported the impact of biomechanical risk factors[7,8,18,20,38,51,63,64,66,106] or individual characteristics[1,3,7,14,18,19,21,27,35,45,67,69,106] on LBP risk. More recently, independent research has investigated the influence of psychosocial work factors[15,18,22,35,74] on LBP risk. While it is clear that workers can be exposed to all of these risk factors simultaneously, few studies have attempted to explore the interactions between physical work factors, psychosocial factors, and individual characteristics as well as their influence on the biomechanical responses of the musculoskeletal system.[22,28,117]

The National Academy of Sciences (NAS)[101] have proposed a conceptual model that acknowledges the potential synergistic contributions of the varied workplace and individual factors in the development of musculoskeletal disorders such as LBP (Figure 1). In this model, workplace issues such as physical workplace design (external loading), organizational factors, and social context can interact to influence the body's biomechanical response, thereby, potentially initiating an injury pathway leading to LBP. Similarly, individual factors inherent to the worker such as personality, size, strength, perception, and the like can interact with the biomechanical system to mediate or exacerbate the influence of the workplace factors on the biomechanical response. Yet, few studies have explored these interactions.

Historically, the workplace factors, individual factors, and biomechanical response components of this human response system have been explored in isolation. The literature is replete with laboratory-based biomechanical studies that have demonstrated how the physi-

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Partial funding for this project was generously provided by Honda of America and the International Society for Biomcehanics.
Device status category: The submitted manuscript does not contain information about medical devices and drugs.
Conflict of interest category: Corporate, industry, and professional organizational funds were received in support of this work. No benefits in any form have been or will be received from a commercial party related directly or indirectly to the subject of this manuscript.

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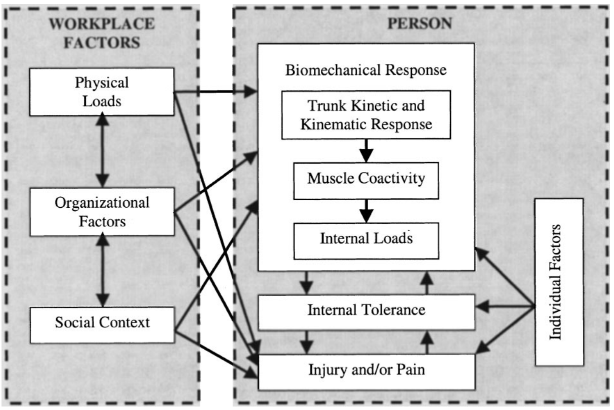

Figure 1. Conceptual model relating potential workplace risk factors to the development of low back pain (adapted from NAS).[101]

cal design of the workplace can lead to increases in spine loading[5,6,23,25,26,30,31,33,37,42,47,76,86,87,94] and their effect on spine loading. Workplace epidemiologic studies[52–56,60,89,90,103,112,113,116,118] have traditionally investigated how the presence of either physical or psychosocial factors might be associated with LBP reporting, but have not directly addressed spine loading issues. Neither approach has addressed the issue of how these factors might intermingle with individual characteristics to affect spine loading, potentially providing a biologically plausible injury pathway.

As society advances, there is a proliferation of more repetitive yet more complex jobs.[101] Many jobs now demand high levels of mental concentration as well as a rapid work pace. These factors have been implicated as organizationally related psychosocial workplace risk factors for LBP. Mental concentration demands have been identified as a risk factor in numerous studies.[2,44,49,55,56,65,70,72,73,114] However, an almost equal number of studies report no association of mental concentration[10,12,32,58,59,115,116] with LBP. This discrepancy might indicate the presence of an interaction with some other variable or variables. For example, it is known that mental concentration is dependent on the complexity of the task.[16] Factors such as the number of alternative actions, insufficient or contradictory data, uncertainty about the consequences of actions, scarcity of time, and probability of failure have been identified as issues that may have an impact on the perceptions of mental workload.[48,95] In this context, mental concentration risk is a function of mental processing demands that depend on the balance between the mental reserves and the demand requirements. Thus, mental demand is a function of the intensity and complexity of the task at hand. We hypothesize that task intensity, and the subsequent mental demands, can be strongly influenced by the timing of task demands. For example, mental processing may have limited consequence when it occurs before physical job requirements, whereas concurrent mental processing and physical task demands may interact to exacerbate stress, resulting in increased biomechanical loading of the musculoskeletal system.

In a similar fashion, rapid job pacing may also draw on the mental reserves of the worker by demanding a conscious effort to keep up with the pace demand. Increased job pacing may have the potential to influence biomechanical loading for two reasons. First, studies have identified increased lift rate as a risk factor for LBP,[20,50,52,63,89,90,103,104] and laboratory studies have shown how spine loading can increase under these conditions.[24,25,39,40,46,54,71,94] Second, forced pacing may also influence the individual through psychosocial mechanisms. The interaction between high mental demands and lack of job control has been associated with higher rates of musculoskeletal disorders and represents mental strain[60–62] (a psychosocial risk factor).[2,44,53,65,99] Forced pacing may lead to cognitive dissonance and the creation of a monotonous work environment, which has been shown to be a risk factor of LBP.[52,56,107,112,113] We hypothesize that cognitive dissonance may amplify the biomechanical response to the other workplace factors through increased coactivation of the torso musculature. Our previous study of biomechanical responses to one type of psychosocial stress supports this contention.[78]

Individual characteristics may also interact with these psychosocial variables to reconcile or exacerbate the body's biomechanical reaction. Previous studies have suggested that crude personality measures can be associated with biomechanical responses to one form of psychosocial stress.[78] Similarly, personality may further influence the biomechanical reaction to the mental processing and pacing *via* a modifying role.[4,118] Thus, the complex nature of the interactions between workplace design, psychosocial factors, individual factors, and biomechanical response may play a significant role in spine loading and the potential for LBP. Gender is also an individual factor that has resulted in differences in biomechanical responses to loads.[31,79]

This brief review has shown that the role of physical workplace design on spine loading has been well documented. However, we do not know how psychosocial and individual factors might additionally influence this loading. The objective of this study was to explore how the interaction of specific psychosocial factors (types of mental processing and work pacing) and individual factors (personality and gender) might further influence the biomechanical response and subsequent spine loading, above and beyond that resulting from physical work design.

■ Methods

Approach. This study evaluated the interaction between the psychosocial variables of mental processing and forced pacing as well as the potential modifying influences of personality and gender on biomechanical loading of the spine during a lifting task. In this study the physical workplace characteristics were held constant since their influence on spine loading is well understood. Mental processing factors and pacing requirements

Table 1. Summary of Gross Anthropometric Measurements and Personality Distribution for the Subjects that Participated in the Study

	Female	Male
	Mean	Mean
Anthropometric measurements		
Age (years)	21.3 ± 2.3	23.3 ± 3.2
Body weight (cm)	62.0 ± 7.8	79.0 ± 11.4
Standing height (cm)	166.6 ± 4.5	178.6 ± 8.0
	Frequency n (%)	Frequency n (%)
Personality distribution		
Extrovert (E)	24 (80.0)	17 (56.7)
Introvert (I)	6 (20.0)	13 (43.3)
Intuitor (N)	14 (46.7)	18 (60.0)
Sensor (S)	16 (53.3)	12 (40.0)
Thinker (T)	11 (36.7)	20 (66.7)
Feeler (F)	19 (63.3)	10 (33.3)
Judger (J)	16 (53.3)	13 (43.3)
Perceiver (P)	14 (46.7)	17 (56.7)

of the work were manipulated. Spine loadings were observed as a function of these variables as well as personality and gender.

Experimental Task. The experimental task was intended to simulate a lifting task requiring various levels of decision making (mental processing) that would be common in a modern distribution center. The physical task required subjects to lift boxes weighing 6.8 and 11.4 kg from a conveyor (sagittally symmetric) to an asymmetric shelf that was either 90° clockwise (CW) or 90° counterclockwise (CCW), as determined by a mental processing task. The box origin was set at a height of 80 cm and a reach distance of 45 cm. The destination was located at a height of 105 cm and a reach distance of 55 cm.

Subjects. The participants in the study were 60 volunteers (30 males and 30 females) who had been asymptomatic of low back pain during the previous year. Selective anthropometric measurements and personality breakdown are shown in Table 1. The participants were paid $60 on study completion. The experimental protocol was approved by the university's institutional review board.

Experimental Design. The study design controlled two psychosocial variables: mental processing and forced pacing of the lifting task. Mental processing was set at two primary levels and two secondary levels. The two primary levels were serial mental processing that required any mental processing decisions to occur before the act of lifting and simultaneous mental processing that required any mental processing decisions to occur concurrently with the lift. The secondary levels consisted of simple and complex demand levels under the serial and simultaneous conditions.

Under the serial mental processing condition, the simple demand level consisted of verbal commands instructing the subject to deliver the box to the CW or CCW destination. The complex demand task within the serial mental processing condition required the subject to read and interpret an 8-digit number off the top of the box, enter the number into a computer, and decide whether to place it in the CW or CCW destination. An 8-digit number was adopted to ensure a relatively difficult mental processing task.[11,96,97,108]

Under the simultaneous mental processing condition, the simple demand level consisted of allowing the subject to place the box in the general vicinity of the destination on a shelf. The complex demand level under the simultaneous mental processing condition required the subject to place the box precisely within a destination target (within a 1.3-cm tolerance) on a shelf, thus requiring continuous vigilance and motor control. An electrical circuit was used to monitor this tolerance. The forced pacing factor was set at two levels for the lifts: slow, occurring at two lifts per minute, and fast, occurring at eight lifts per minute. Subjects performed all the combinations of conditions, resulting in eight unique combinatorial conditions. Each condition was repeated twice and presented in a random order.

The individual factors of personality and gender were considered as blocking factors in the experimental design. The Myers–Briggs Type Indicator (MBTI)[100] form M was used to characterize the subject's personality type. Each primary personality trait is thought to be associated with the response of the individual to certain types of work tasks.[17,68]

The measured (dependent) variables were the biomechanical responses and subsequent spine loads during each lift. Biomechanical responses consisted of the muscle activities of the trunk muscles and the trunk kinematics (peak three-dimensional trunk positions, velocities, and accelerations). The three-dimensional trunk moments and spine loads were determined using the EMG-assisted model developed over the past 18 years in the biodynamics laboratory.[25,33,39–41,57,79,81–85,88,92–94,98,105] The model provides measures of the trunk moments as well as compression, lateral shear, and anteroposterior (AP) shear forces at the spine at L5–S1.

Apparatus. A lumbar motion monitor (LMM)[80] measured the instantaneous three-dimensional trunk motion characteristics during the lifting tasks. A force plate and electrogoniometric system was used to estimate accurately the moments supported by the trunk by translating and rotating the forces and moments measured at the center of the force plate to L5–S1.[34] Electromyographic (EMG) activity was collected from the five pairs of trunk muscles (right and left pairs of latissimus dorsi, erector spinae, rectus abdominus, external obliques, and internal obliques) through the use of bipolar silver–silver chloride surface electrodes (placement details are described elsewhere).[98] The EMG signals were preamplified, high-pass filtered at 30 Hz, low-pass filtered at 1000 Hz, rectified, and processed *via* a 20-ms sliding window hardware filter.

Procedure. On arrival at the biodynamics laboratory, the subjects were briefed about the study. They then read and signed a consent form and completed the MBTI. The surface electrodes were applied to the subject using standard EMG techniques.[75,102] Next, standard maximum exertions were performed for EMG normalization purposes.[91] Subjects were then fitted with a LMM and positioned on the force plate. Experimental conditions were then performed. Pacing was controlled by a computer tone that signaled when to lift the next box.

Statistical Analyses. Trunk kinematics converted from the LMM, normalized EMG activities, and measured kinetic data were inputted into the EMG-assisted model to obtain the predicted trunk moments and spine loads. Descriptive statistics of

Table 2. Statistical Significant Summary and Data: Mean of the Peak Spine Loads (N) as a Function of Serial Mental Processing, Simultaneous Mental Processing, and Pacing*

Main Effects	Peak Compression	Peak Lateral Shear	Peak AP Shear
Serial mental processing	***P* = 0.05**	***P* = 0.35**	***P* = 0.11**
Simple	4402.3 ± 1443.4	378.0 ± 378.2	670.7 ± 317.4
Complex	4471.8 ± 1483.0	386.6 ± 432.3	656.0 ± 302.7
Simultaneous mental processing	***P* = 0.0001**	***P* = 0.0001**	***P* = 0.0001**
Simple	4092.7 ± 1212.6	302.5 ± 257.6	623.4 ± 272.3
Complex	4781.4 ± 1605.5	463.1 ± 500.7	703.4 ± 339.4
Pacing	***P* = 0.0001**	***P* = 0.02**	***P* = 0.0001**
Slow (2 lifts/min)	4231.7 ± 1387.5	373.6 ± 404.0	633.2 ± 268.2
Fast (8 lifts/min)	4642.4 ± 1508.6	392.0 ± 408.2	693.5 ± 344.6
Interactions			
Serial–simultaneous	*P* = 0.69	*P* = 0.38	***P* = 0.001** **Figure 3**
Serial–pacing	***P* = 0.01** **Figure 2**	*P* = 0.44	*P* = 0.90
Simultaneous–pacing	*P* = 0.32	*P* = 1.00	*P* = 0.54
Serial–simultaneous–pacing	*P* = 0.19	*P* = 0.54	*P* = 0.50

* *P* values are reported for analysis of variance procedures, with bolded values being significant at 0.05.
AP = anteroposterior.

all the dependent variables were determined as a function of the experimental conditions. A repeated-measures split-plot analysis of variance (ANOVA) was performed for all the dependent variables, with all significant effects being further analyzed using Tukey multiple pairwise comparisons.

Results

Spine Loads

Both mental processing demands factors and pacing condition had an impact on the three-dimensional spine loads (Table 2). Only a small increase (~70 N) in the compression forces was noted as a function of complex demands under the serial processing condition, as compared with the simple demand serial condition. Complex demands under the simultaneous mental processing condition resulted in much greater increases in spine loads (160 N of lateral shear, 80 N of anteroposterior shear, and 700 N of compression) above those of the simple demand simultaneous mental processing condition. Increasing the forced pace produced greater lateral shear (by 20 N), anteroposterior shear (by 60 N), and compression loads (by 410 N). As shown in Figure 2, the impact of the serial mental processing demands depended largely on the forced-pace rate, with a major increase in spine compression occurring under the fast-pace condition. A significant interaction was also noted between the serial and simultaneous mental processing conditions with respect to anteroposterior shear forces (Figure 3).

Biomechanical Responses

Increased spine loading occurs as a result of changes in trunk kinetics, kinematics, and muscle activities. Numerous kinetic and kinematic differences were observed as a function of the experimental conditions. Significant differences are summarized in Table 3. In general, complex demands under the simultaneous mental processing condition and faster pacing resulted in greater trunk moments (up to 25% increases) as well as slightly greater trunk and hip motions. More complex changes in muscle activities occurred as a function of the experimental conditions. The mental processing condition and pacing had a varying impact on the trunk muscle coactivity, as

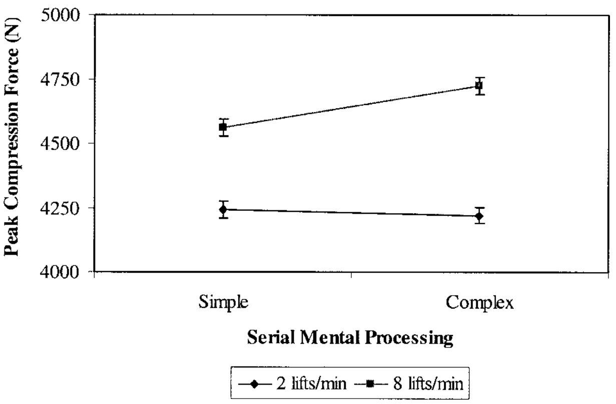

Figure 2. Peak compression forces as a function of serial mental processing and pacing. Means and standard errors are displayed.

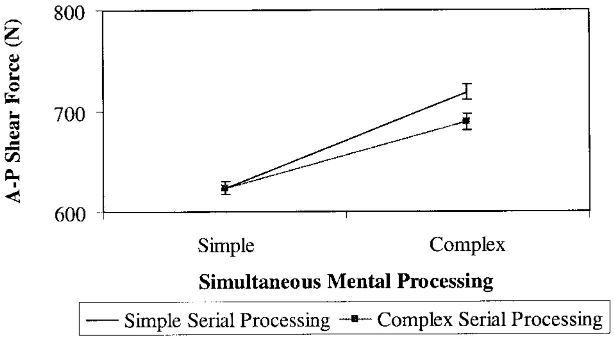

Figure 3. Peak anteroposterior shear forces as a function of serial and simultaneous mental processing. Means and standard errors are displayed.

Table 3. Summary of Statistical Results for Trunk Kinematics and Kinetics as a Function of Serial Mental Processing, Simultaneous Mental Processing, and Pacing

	Trunk Moments			Trunk Posture			Trunk Velocity			Hip Posture		Hip Velocity	
Effect	SAG	LAT	TWT	SAG	LAT	TWT	SAG	LAT	TWT	TILT	ROT	TILT	ROT
Serial mental processing	0.16	0.21	0.61	0.71	**0.02**	0.59	0.93	0.14	**0.0001**	**0.005**	0.09	0.07	**0.0001**
Simultaneous mental processing	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.04**	**0.003**	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0002**
Pacing	**0.0001**	0.09	**0.003**	**0.0002**	**0.0007**	0.80	**0.0001**	**0.0001**	**0.0001**	**0.05**	**0.03**	**0.0001**	**0.0001**
Serial–simultaneous	**0.0003**	0.47	0.70	**0.0001**	0.54	0.47	**0.01**	0.37	0.99	1.00	0.30	0.77	**0.03**
Serial–pacing	**0.01**	0.16	**0.05**	**0.04**	0.14	0.08	**0.0001**	0.77	**0.002**	0.84	0.71	**0.01**	**0.0001**
Simultaneous–pacing	**0.01**	0.96	0.43	**0.0001**	0.94	0.65	0.56	0.23	0.49	0.59	0.17	0.82	**0.005**
Serial–simultaneous–pacing	0.08	0.95	0.68	**0.01**	0.69	0.69	0.83	0.62	0.69	0.44	0.35	0.24	**0.01**

P values are reported for analysis of variance procedures, with bolded values being significant at 0.05.
SAG = sagittal; LAT = lateral; TWT = twist; TILT = Hip sagittal flexion; ROT = Hip rotation.

shown in Table 4. Serial mental processing had an impact on the activity of three trunk muscles (right erector spinae and right and left internal oblique) to a very minor degree (MVC, ~1%). Complex demands under the simultaneous mental processing condition increased the muscle activities in all 10 of the trunk muscles from 2% to 7%, as compared with those of the simple demand condition. Fast pacing produced significantly more activity in the extensor muscles (MVC, 2–5%) and in the flexor muscles (MVC, 1–2%). The activity of the internal oblique muscles was greatest when serial mental processing and fast pacing occurred (Figure 4).

Individual Factors

The effects of the individual factors are shown in Table 5. Females experienced increased spine loading in all dimensions, as compared with males. The effects of personality traits are also displayed in Table 5. This analysis shows varying responses as a function of personality traits, with differences of up to 17% between opposite traits. These personality trait effects are above and beyond the effects of gender. Biomechanical responses associated with these individual characteristics are also shown in Table 5.

■ Discussion

This study has helped us begin to understand some of the biomechanical ramifications of psychosocial stress and individual factors affecting the biomechanical loading of the spine. Furthermore, this study is a first step in understanding the interaction between several diverse occupational risk factors that operate on the complex human system, and that under certain conditions can lead to LBP.

The current study has demonstrated that significant increases in spine compression can occur in response to complex mental demands when they occur before the actual lift. However, these increases in loading are rather modest and most likely not very meaningful from a biomechanical standpoint. However, when complex mental tasks are performed simultaneously in conjunction with the lift, large, biomechanically meaningful increases in three-dimensional spine loadings are observed. In addition, rapid job pacing, independent of mental processing, can increase three-dimensional spinal loads, but not to the extent that complex simultaneous mental processing can increase the loads on the spine. Hence, the order of influence on spinal loading is first complex simultaneous mental processing, followed by rapid pacing, then by

Table 4. Statistical Significant Summary and Data: Mean (Standard Deviation) of the Muscle Activities of the 10 Trunk Muscles as a Function of Serial Mental Processing, Simultaneous Mental Processing, and Pacing*

	Left Latissimus Dorsi	Right Latissimus Dorsi	Left Erector Spinae	Right Erector Spinae	Left Rectus Abdomominus	Right Rectus Abdomominus	Left External Oblique	Right External Oblique	Left Internal Oblique	Right Internal Oblique
Serial mental processing	*P* = 0.91	*P* = 0.09	*P* = 0.33	***P* = 0.01**	*P* = 0.43	*P* = 0.60	*P* = 0.12	*P* = 0.82	***P* = 0.003**	***P* = 0.0001**
Simple	0.34 (0.28)	0.32 (0.25)	0.73 (0.34)	**0.70** (0.26)	0.16 (0.15)	0.14 (0.14)	0.28 (0.19)	0.27 (0.17)	**0.55** (0.26)	**0.49** (0.23)
Complex	0.34 (0.27)	0.33 (0.25)	0.74 (0.34)	**0.71** (0.27)	0.15 (0.14)	0.14 (0.14)	0.28 (0.19)	0.27 (0.17)	**0.57** (0.27)	**0.50** (0.25)
Simultaneous mental processing	***P* = 0.0001**	***P* = 0.0001**	***P* = 0.0001**	***P* = 0.0001**	***P* = 0.0001**	***P* = 0.0001**	***P* = 0.0001**	***P* = 0.0001**	***P* = 0.0001**	***P* = 0.0001**
Simple	**0.31** (0.24)	0.29 (0.22)	**0.71** (0.32)	**0.69** (0.25)	**0.14** (0.13)	**0.13** (0.14)	**0.25** (0.17)	**0.24** (0.16)	**0.54** (0.26)	**0.47** (0.24)
Complex	**0.38** (0.31)	**0.36** (0.28)	**0.76** (0.35)	**0.73** (0.27)	0.17 (0.16)	**0.15** (0.14)	**0.31** (0.20)	**0.29** (0.18)	**0.58** (0.27)	**0.51** (0.24)
Pacing	***P* = 0.0001**	***P* = 0.0001**	***P* = 0.0001**	***P* = 0.0001**	*P* = 0.12	***P* = 0.01**	***P* = 0.0001**	***P* = 0.0001**	***P* = 0.0001**	***P* = 0.0001**
Slow (2 lifts/min)	**0.33** (0.27)	**0.31** (0.24)	**0.71** (0.33)	**0.68** (0.26)	0.15 (0.15)	**0.14** (0.14)	**0.27** (0.18)	**0.26** (0.16)	**0.53** (0.25)	**0.47** (0.23)
Fast (8 lifts/min)	**0.35** (0.28)	**0.34** (0.26)	**0.76** (0.35)	**0.73** (0.27)	0.16 (0.15)	**0.15** (0.14)	**0.29** (0.20)	**0.27** (0.17)	**0.59** (0.27)	**0.52** (0.25)

* *P* values are reported for analysis of variance procedures, with bolded values being significant at 0.05.

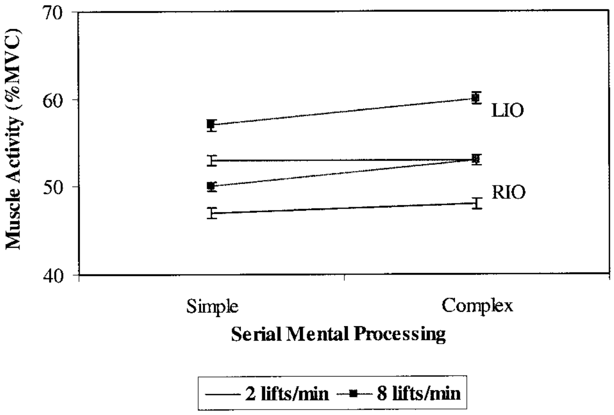

Figure 4. Muscle activity of the right (RIO) and left (LIO) internal oblique muscles as a function of serial mental processing and pacing. Means and standard errors are displayed.

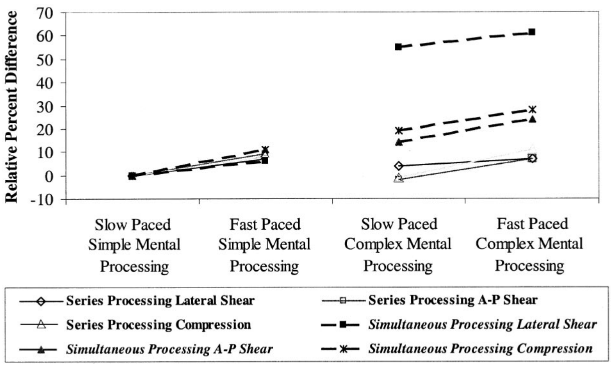

Figure 5. Impact of series and simultaneous mental processing on the spinal loads. Values are relative to the simple mental demanding task at the slow rate.

serial complex mental processing. Finally, when pacing increases under serial mental processing conditions, spine loading also increases significantly, indicating a meaningful interaction between psychosocial variables. The overall magnitude of these effects can be appreciated in Figure 5, which indicates that slight increases in loading are observed simply as a function of pacing. However, the impact of pacing is much greater (up to 50% greater) when pacing is increased under simultaneous complex conditions. Hence, mental processing complexity, simultaneous mental processing, and rapid pacing all can act as catalysts for increased spine loading. However, combinations of these catalysts can interact to increase spine loading markedly.

The mechanism by which these psychosocial factors influence spine loading must be considered. The common feature among these factors that increase spine loading is that they all constrain the subject in the temporal domain, thus causing the subject to react physically in a short time given the task demand most likely leading to mental stress. Mental stress may be one potential mechanism through which mental processing initiates a biomechanical response.[78] This hypothesis is consistent with the Karasek et al's[60–62] job strain model, which states that the conditions with the greatest mental demand and lowest control would be expected to produce the largest biomechanical response. In our study, the time constraints resulted in less controlled movements, as demonstrated by greater off-plane moments and more extreme trunk and hip motions. Thus, intense simultaneous mental processing resulted in a large biomechanical cost to the spine. These kinetic and kinematic changes were accompanied by greater trunk muscle coactivities that resemble guarding behavior in patients with low back pain.[77] In previous studies, these increases in movements and coactivities were shown to result in increased spine loading.[25,40–42] Hence, increasing the levels of these psychosocial variables is associated with clearly defined biomechanical pathways to increased spine loading.

The impact of these timing issues was further influenced by individual factors (Table 4). Simultaneous processing had a greater impact on the biomechanical response of females than that of males. We expect that females were more strained than males due to their smaller size. The addition of mental processing during the lift may have further magnified the spine loading response. Epidemiologic studies suggest that high mental concentration is linked to increased reporting of LBP for

Table 5. Relative Percentage Differences Between Simple and Complex Simultaneous Mental Processing as a Function of Gender and Personality Traits for Spine Loads, Trunk and Hip Kinematics, Trunk Kinetics, Agonistic Muscle Activity, and Antagonistic Muscle Activity

	Spine Loads			Biomechanical Responses				
Individual Characteristic	Compression	Lateral Shear	AP Shear	Trunk Kinematics	Hip Kinematics	Trunk Moments	Agonistic Muscle Activity	Antagonistic Muscle Activity
Females to males	11.8	7.2	4.8	−2.5 to 3.0	2.7 to 8.6	−0.6	2.9 to 16.0	1.8 to 9.8
Extraverts to introverts	7.8	12.0	2.4		10.0	1.0	3.1 to 9.8	9.0 to 20.4
Sensors to intuitors		15.2	2.7	0.8 to 2.0	−2.1 to −6.4		0.8 to 6.3	
Feelers to thinkers	6.1	17.3		4.1 to 9.7	−2.2	−2.5 to −3.3	−3.2 to 2.0	7.9 to 9.3
Judgers to perceivers	3.4			2.5		3.6 to 4.5	6.8	−8.1

Numbers represent the additional percentage change of the first characteristic relative to the second characteristic.
AP = anteroposterior.

females but not for males.[13,14,45,74,119] Furthermore, the combination of time pressure and high workload is reported to be associated with LBP for females only.[36] Thus, our results potentially provide biologic evidence for a gender predisposition to mental processing demands, particularly when they are synchronized with greater relative biomechanical loading.

Recent biomechanical studies[4,78,118] have demonstrated that people of certain personality types respond to adverse interpersonal situations by recruiting their muscles to a greater degree, resulting in greater spine loading. In one study,[78] introverts responded with significantly greater spine loading. Interestingly, in the current study, the exact opposite response was noted in that extroverts were more affected by the temporally related pressures and demonstrated greater spine loadings than introverts. This may demonstrate how different personality factors respond to different aspects of psychosocial stress. Numerous other personality-related differences in spine loading were also noted, indicating that these temporally related pressures affect different personality types in different ways. Hence, it appears that individual characteristics act in a complex manner to serve as a further catalyst with the psychosocial factors observed in this study. Here again, we are just beginning to understand the impact of personality on the response of the human system to psychosocial stress.

We attribute the richness of our findings to several features unique to this study. First, the sample size was extraordinarily large for a complex biomechanical study. This afforded us adequate statistical power to explore the complex nature of psychosocial and individual factors at multiple levels. Second, the experimental design sought purposely to set the experimental levels at disparate levels that would identify significant differences if they were present. Third, the biomechanical model used to monitor spine forces was a biologically assisted model that is very sensitive to subtle changes in muscle recruitment, body movement, and the externally applied load. This model is also "tuned" to the individual's anthropometric characteristics,[57,88] thus permitting a high degree of biomechanical fidelity. The model has been well developed and thoroughly reported in the literature.[25,33,39–41,57,79,81–85,88,92–94,98,105]

Several potential limitations need to be considered when the results of the current study are interpreted. First, the current study evaluated only short-term responses to the workplace stressors that may underrepresent the "true" impact. Long-term exposure to these exposures may be more detrimental, in that precision placement may result in muscle fatigue, further changing the way a person responds to the workplace.[82,109,110] Next, mental fatigue may also magnify the impact of mental processing on the biomechanical responses. This was unexplored in the current study. Finally, the subjects in this study consisted primarily of people in their early twenties. Future studies might include subjects of a broader age range.

Although the current study provides an initial evaluation of the impact that work-related mental processing has the effects of spine loading, it merely scratches the surface. There are still many potential psychosocial and individual interactions left to explore that may have an impact on biomechanical loading of the spine. Issues such as the relative contributions of these factors, and whether thresholds exist that initiate their influence still need to be explored.

In conclusion, we have found that mental stress appears to act through time pressure limits, resulting in the overreaction of the musculoskeletal system. This overreaction manifests itself through less controlled trunk motions and increases in torso muscle coactivation, resulting in increased three-dimensional spine loading. Hence, these results suggest a potential mechanism by which psychosocial stress may increase lumbar spine load as a result of modern work demands and may help to explain the potential biomechanical mechanisms behind occupational risk.[13,32,34,37,72,108]

■ Key Points

- Mental processing occurring *prior* to the lift results in minor increases in spine compression.
- Mental processing occurring *simultaneous* to the lift results in biomechanically meaningful increases in three-dimensional spine loads.
- Rapid pacing independently increases three-dimensional spine loads as well as interacts with mental demands.

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