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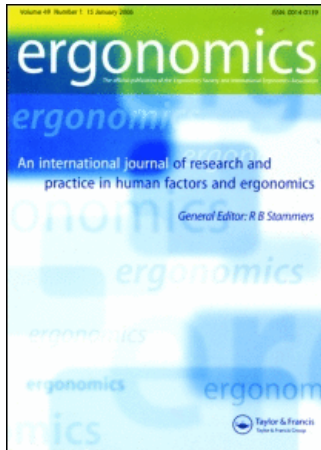
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The influence of lift frequency, lift duration and work experience on discomfort reporting

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Discomfort surveys are commonly used to assess risk in the workplace and prioritize jobs for interventions before an injury or illness occurs. However, discomfort is a subjective measure and the relationship of discomfort to work-related factors is poorly understood. The objective of this study was to understand how reports of discomfort relate to work-related risk factors for the low back. A total of 12 novice and 12 experienced manual materials handlers performed repetitive, asymmetric lifts at different load levels and at six different lift frequencies throughout an 8-h exposure period. Discomfort was recorded hourly throughout the day. Analyses were performed to determine which experimental factors influenced reporting of discomfort and if discomfort trends matched spine loading trends. Novice lifters reported significantly higher discomfort levels than experienced subjects. They also reported increases in discomfort as moment exposure increased and as the exposure time increased. Novices lifting at 8 Nm load moment level reported increased discomfort from 0.07 to 0.63 by the end of the day, at 36 Nm they reported an increase from 0.04 to 0.40 and at 85 Nm they reported an increase from 0.37 to 3.06. Experienced subjects, on the other hand, reported low levels of discomfort regardless of moment exposure, lift frequency or exposure duration. The reported discomforts were generally unrelated to the biomechanical loading on the spine. Discomfort reporting appears to be more a reflection of experience than of work risk factor exposure. Experienced subjects may have more efficient motor patterns, which reduce spinal load and thus discomfort. Novice subjects seemed to have a lower threshold of discomfort. Caution is needed when using discomfort reporting as a means to identify jobs in need of interventions, in that biomechanical loading may not be accurately represented. Discomfort should only be used as a supplement to objective measures, such as spinal loading, to assess the risk of low back disorders.

Keywords: Low back pain; Spine loads; Modelling; Discomfort

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1. Introduction

Low back disorders continue to represent the most common and costly work-related health problem facing society today. A proactive approach to controlling occupationally related low back disorders typically requires a survey of the workplace in order to identify jobs in need of intervention. These surveys often involve discomfort surveys that attempt to identify trends in discomfort reporting among the workers within particular jobs. Conceptually, discomfort measures are an attractive risk indicator because they use the body's feedback system to elucidate potential problems and are relatively easy to collect. Many risk assessment tools utilize discomfort measures as a starting point for further assessments.

The ability to easily collect subjective information has led many researchers to employ discomfort assessments for comparing work conditions such as workstation settings, types of manual tools, body postures and work rates (Cameron 1996). Discomfort ratings can give an indication of subjective preferences of one system over another. Although much of the literature has reported discomfort-based preferences in work (Snook 1985, Ciriello *et al.* 1990, Snook and Ciriello 1991, Ayoub and Dempsey 1999), there is little understanding of how these discomforts relate to typical workday exposures and spine loading.

Risk assessment tools are often used to redesign workstations, prioritize areas in need of ergonomic intervention and minimize risk factors. For this reason, every attempt must be made to make risk assessment tools accurate. If discomfort is indeed to be used as a risk assessment tool, as it currently is in many cases (Cameron 1996, Straker *et al.* 1997a,b), then it should be determined what workplace factors influence the reporting of discomfort levels.

The assumption underlying discomfort measures is that the discomfort reports reflect the early perception of pain that is related to excessive loading on the biomechanical system and, therefore, might be used to identify problematic work situations. Discomfort information makes use of the body's own feedback system (Straker 1999). Discomfort measures also serve as the underpinning for psychophysical measures of work acceptance (Snook and Ciriello 1991, Keyserling 2000). However, discomfort is a subjective experience and may be influenced by many factors other than the physical work, such as experience, expectations, attitudes, physiological reactions and non-physical (mental) stress. Thus, discomfort measures may provide suggestive information regarding workplace stress that could be unrelated to the physical requirements of the job. There is little information about how discomfort reports correlate with physical requirements of the job, especially over extended work periods. Furthermore, no studies have been found in the literature that assess spine loading throughout a typical (8 h) workday. Hence, it is unclear whether subjective measures of discomfort could reflect the biomechanical change in spine loading.

The aim of this study was to determine which workplace factors influence the reporting of discomfort levels and to examine the extent of their influence. A secondary objective was to correlate the perception of discomfort with previously reported spinal loading (Marras *et al.* 2006) in an attempt to establish the feasibility of using subjective discomfort ratings as a reflection of loading on the lumbar spine.

2. Methods

2.1. Approach

The purpose of this study was to assess how discomfort reporting changes in response to subject experience, load weight, lift frequency and duration of exposure over an 8-h

period of lifting activity. This study required both experienced and inexperienced subjects to lift under one of three weight conditions (moment exposure) over 6 different days, where a different lift frequency was assigned on each day. Subjects were asked to lift for an entire 8-h period. Discomfort ratings were collected hourly over the exposure period. Spine loading was also assessed during the exposure period and was reported in detail in a separate publication (Marras *et al.* 2006).

2.2. Subjects

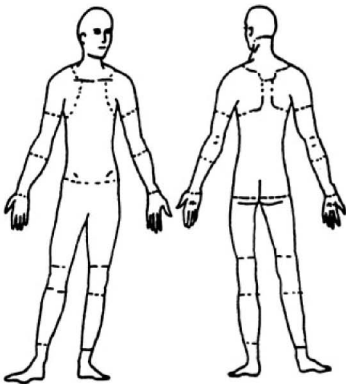
A total of 24 subjects with no prior history of low back pain volunteered for this study and received an hourly wage plus a bonus for finishing all test conditions. For the study, 12 novice subjects (with no manual material handling experience) were recruited from university students and 12 experienced manual material handlers (with at least 1 year experience) were recruited from local grocery stores and distribution centres. The two experience levels were chosen so that results could be applicable to a wide range of manual material handling workers. The novice group included nine males and three females, whereas the experienced subjects were all males. The average age was 24 (SD 3) years for the novice subjects and 23 (SD 4) years for the experienced group. The average stature and weight of the novices were 177 (SD 8) cm and 75 (SD 15) kg, respectively and for experienced subjects were 177 (SD 4) cm and 81 (SD 16) kg, respectively.

2.3. Experimental design

The experimental design consisted of a repeated measures design with two between-subjects factors (load moment and experience) and one within-subjects factor (lift frequency). The independent variables included experience level, load moment, lift frequency and time block. The initial load moment to which the subject was exposed was defined by one of three initial static load moment levels (8, 36 and 85 Nm). In order to control this initial moment exposure, the subject was positioned on a force plate relative to the position origin of one of three loads (1.1, 4.9 or 11.7 kg). Subjects were exposed to only one of the load moment conditions but were tested under all frequency conditions. The lift frequency had six levels: 2, 4, 6, 8, 10, 12 lifts/min. Subjects were tested in six separate 8-h sessions, once under each frequency condition. Presentation order of the lift frequency conditions was randomized and balanced over the sessions (but not for each subject since two subjects worked in each session). All test sessions were separated by at least 1 d of rest. The effect of time was evaluated by dividing the 8-h work day into four 2-h blocks of time.

The dependent measures consisted of discomfort reports via a discomfort survey (figure 1). The survey was administered every hour over the 8 h data collection period and at the beginning and end of the break periods. The survey required the subject to report perceived discomfort on a scale of 0 to 6, where 0 was no discomfort and 6 was the highest discomfort. Back discomfort was the variable of interest in this study. The survey divided back discomfort reporting into the upper and the lower back. For analysis purposes, these two categories were combined via summation.

The 3-D spine loading predicted by an electromyography (EMG)-assisted biomechanical model was also collected during the experimental task lifts and has been reported in a separate publication (Marras *et al.* 2006). Peak compression, anterior–posterior (AP) shear and lateral shear forces on L5/S1 were all predicted by the model. Spine loading



Discomfort Level

	None			Some			High
Neck	0	1	2	3	4	5	6
Shoulder	0	1	2	3	4	5	6
Elbow/Forearm	0	1	2	3	4	5	6
Hand/Wrist	0	1	2	3	4	5	6
Fingers	0	1	2	3	4	5	6
Upper Back	0	1	2	3	4	5	6
Low Back	0	1	2	3	4	5	6
Thigh/Knee	0	1	2	3	4	5	6
Low Leg	0	1	2	3	4	5	6
Ankle Foot	0	1	2	3	4	5	6

Check the word which best describes your discomfort:

- Pain
- Swelling
- Stiffness
- Numbness
- Tingling
- Sweating
- Weakness
- Redness
- Cramping

Figure 1. Discomfort survey.

information was collected every 10 min throughout the 8-h session. To allow for comparisons between subjects, spinal loading was normalized to the subject's body weight.

2.4. Experimental task

Subjects performed whole body free-dynamic lifts, representative of a common repetitive industrial lifting operation (Marras *et al.* 1993). The task involved a vertical origin height of 88 cm, vertical destination height of 121 cm, origin moment arm distance of 74 cm and an asymmetry of 90°. Two subjects (drawn from the same experience group) performed the experimental task simultaneously. One subject lifted the load from a conveyor origin

and placed it on another destination conveyor where it was delivered to the other subject. The second subject performed the identical task at the other end of the conveyor system (figure 2). The subject lift frequency was governed by a metronome that produced a tone when a lift was to take place. The speed of the lift (between tones) was left to the discretion of the subject. The task was repeated at the session's specified frequency for 8 h with typical industrial break schedules (two 15 min breaks and 0.5 h lunch break). The experiment was approved by the University Institutional Review Board.

2.5. Data normalization and analyses

Statistical significance was assessed using a repeated measures analysis of covariance structure. In this analysis, fixed effects consisted of lift frequency and time block. Subject experience and load moment conditions were considered between-subject variables. Because both random and fixed effects were present, the mixed procedures analysis of SAS was employed to identify significant effects and significant contrasts for their main and interactive effects on the discomfort level and peak compression, AP and lateral shear forces on the L5/S1. In this study, statistical significance was defined as an alpha level of 0.05.

3. Results

Discomfort ratings were affected by both the independent factors as well as by their interactions. Table 1 summarizes the significant influences upon reported discomfort. In general, discomfort was significantly influenced by moment (load) exposure, experience and time of exposure, as well as by many of the interactions with these factors and the frequency by time interaction.

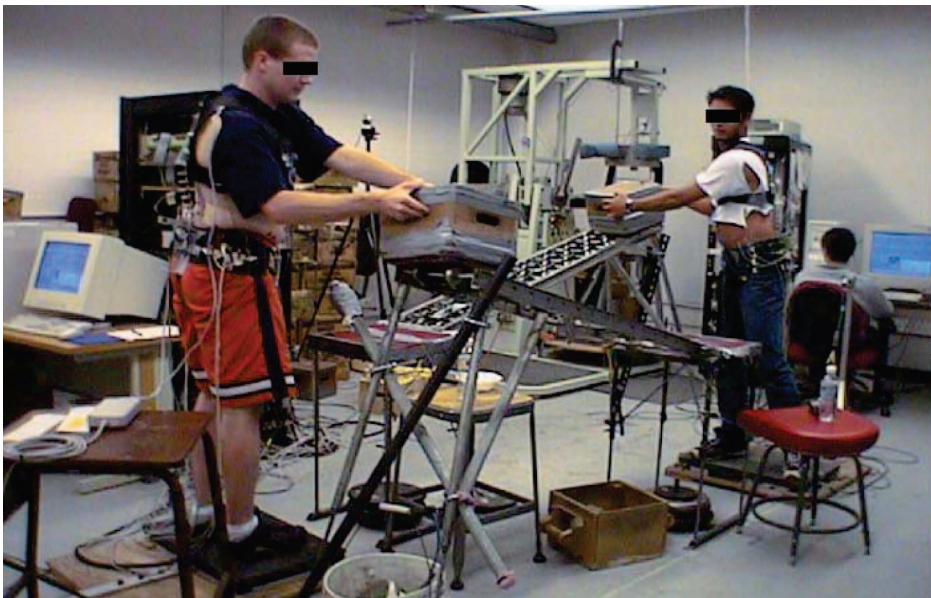


Figure 2. Experimental apparatus used to test two subjects simultaneously.

The influence of moment exposure upon discomfort reporting is shown in figure 3. Overall, the 85 Nm exposure resulted in 0.90 (1.45) on the discomfort rating, which is significantly higher ($p < 0.0001$) than for the 8 Nm and 36 Nm exposures (0.21 (0.55) and 0.14 (0.43), respectively). No significant difference in discomfort was found between the 8 Nm and 36 Nm exposures.

Experience level also played an important role in discomfort reporting, with inexperienced subjects reporting a discomfort level that was significantly higher ($p < 0.0001$) than that reported by experienced subjects (0.73 vs. 0.11).

Table 1. Statistical results of the main and interactive effects of experimental factors on perceived discomfort.

Effect	Degree of freedom	F-value	<i>p</i> -value
Moment	2	23.01	<0.0001†
Experience	1	38.45	<0.0001†
Moment*Experience	2	13.82	0.0002†
Frequency	5	2.17	0.0639
Frequency*Moment	10	3.35	0.0010†
Frequency*Experience	5	1.27	0.2821
Frequency*Experience*Moment	10	1.85	0.0627
Time	3	95.17	<0.0001†
Moment*Time	6	41.26	<0.0001†
Experience*Time	3	56.31	<0.0001†
Moment*Experience*Time	6	18.73	<0.0001†
Frequency*Time	15	2.39	0.0030†
Frequency*Moment*Time	30	2.13	0.0009†
Experience*Frequency*Time	15	0.63	0.8466
Experience*Frequency*Moment*Time	30	0.92	0.5910

†Indicates significant *p* value.

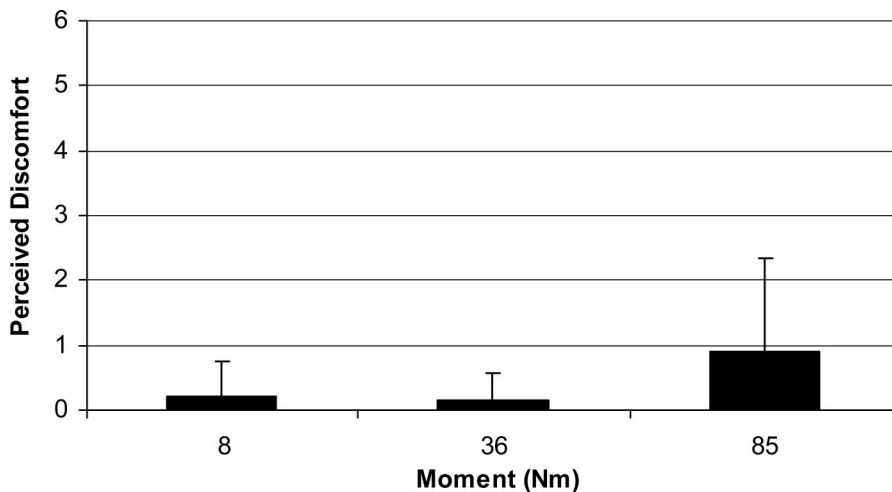


Figure 3. Main effect of moment on perceived discomfort. (Error bars represent standard deviation.)

The interactive effect of moment and experience indicated that the experienced subjects perceived the same level of discomfort regardless of moment exposure, whereas the novice subjects responded more strongly to the 85 Nm moment exposure condition (figure 4).

The main effect of exposure time on discomfort reporting indicated that subjects reported greater discomfort as exposure time increased (figure 5). However, several exposure time interactions significantly influenced discomfort reporting. The interactive effect of moment and time (figure 6) indicated that within the time exposure periods, the

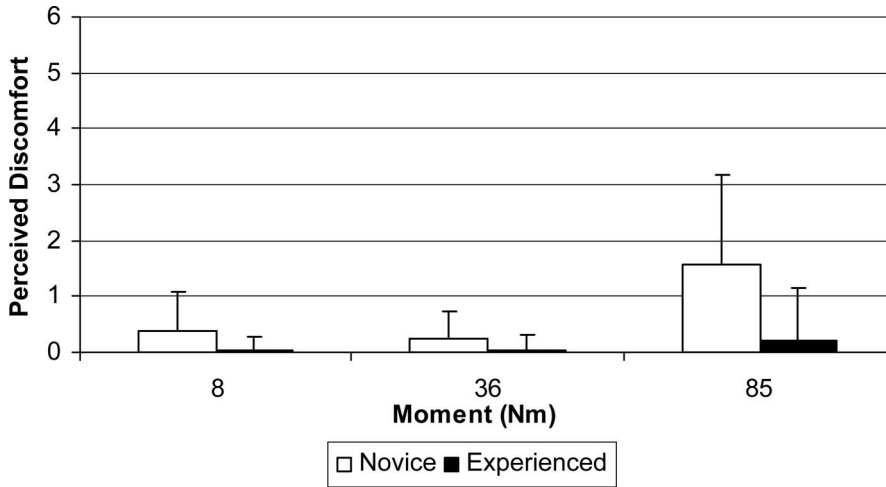


Figure 4. Interactive effect of moment and experience on perceived discomfort. (Error bars represent standard deviation.)

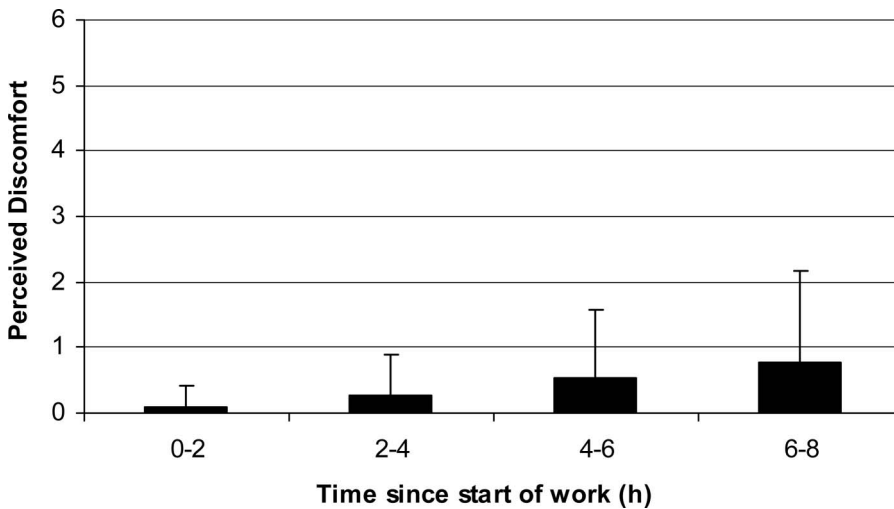


Figure 5. Main effect of time of day on perceived discomfort. (Error bars represent standard deviation.)

85 Nm condition was responsible for monotonic increases in discomfort reporting with each successive time period, whereas the other, lower, moment exposure conditions did not produce significantly different discomfort responses regardless of the time of exposure. In addition, the interactive effect of experience and time (figure 7) showed that only the novices reported significantly increasing higher discomfort levels as the day progressed. Experienced subjects reported similar, low levels of discomfort regardless of

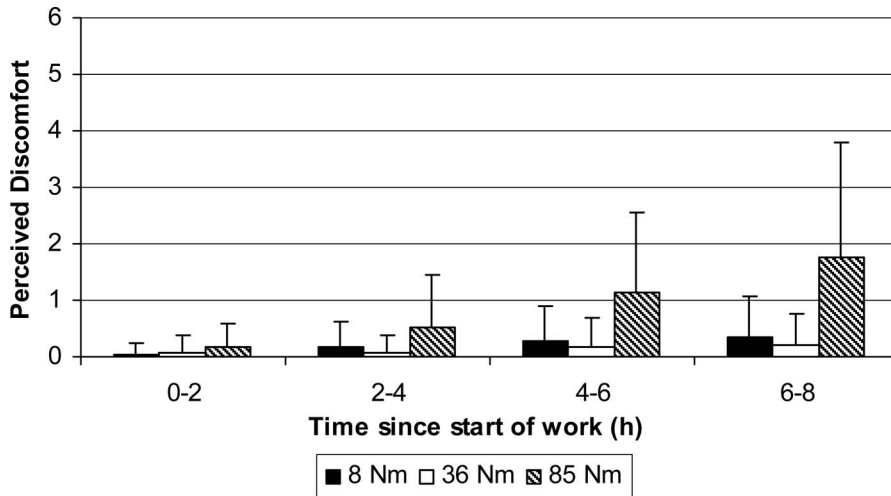


Figure 6. Interactive effect of moment and time on perceived discomfort. (Error bars represent standard deviation.)

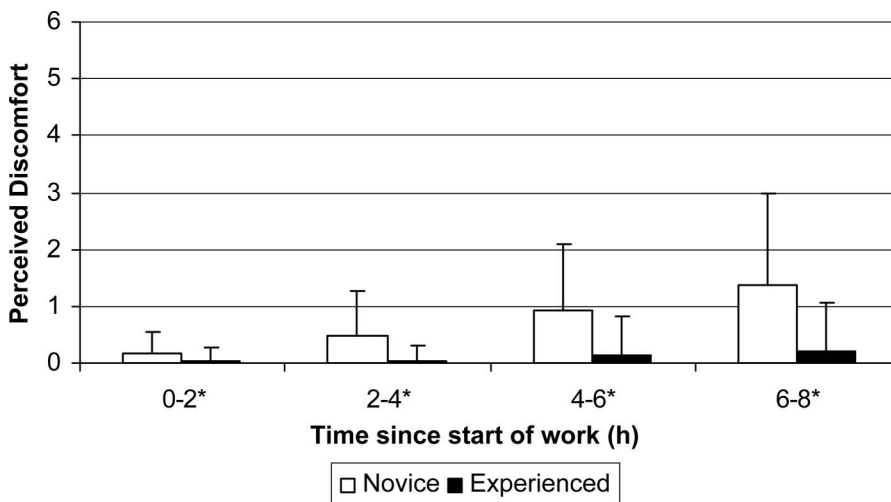


Figure 7. Interactive effect of experience and time on perceived discomfort. *Indicates significant difference between novice and experienced subjects. (Error bars represent standard deviation.)

the exposure time. The three-way interactive effect of moment, experience and exposure time confirmed that the increase in discomfort reporting was due to the inexperienced subjects and also indicated that the high moment exposure condition (85 Nm) was primarily associated with discomfort in the inexperienced group of subjects (figure 8).

The interactive effect of lift frequency, time of lifting exposure and moment was also statistically significant (figure 9). At the 8 Nm and 36 Nm moment levels, perceived discomfort did not show any significantly increasing trends over the 2-h time blocks as lift

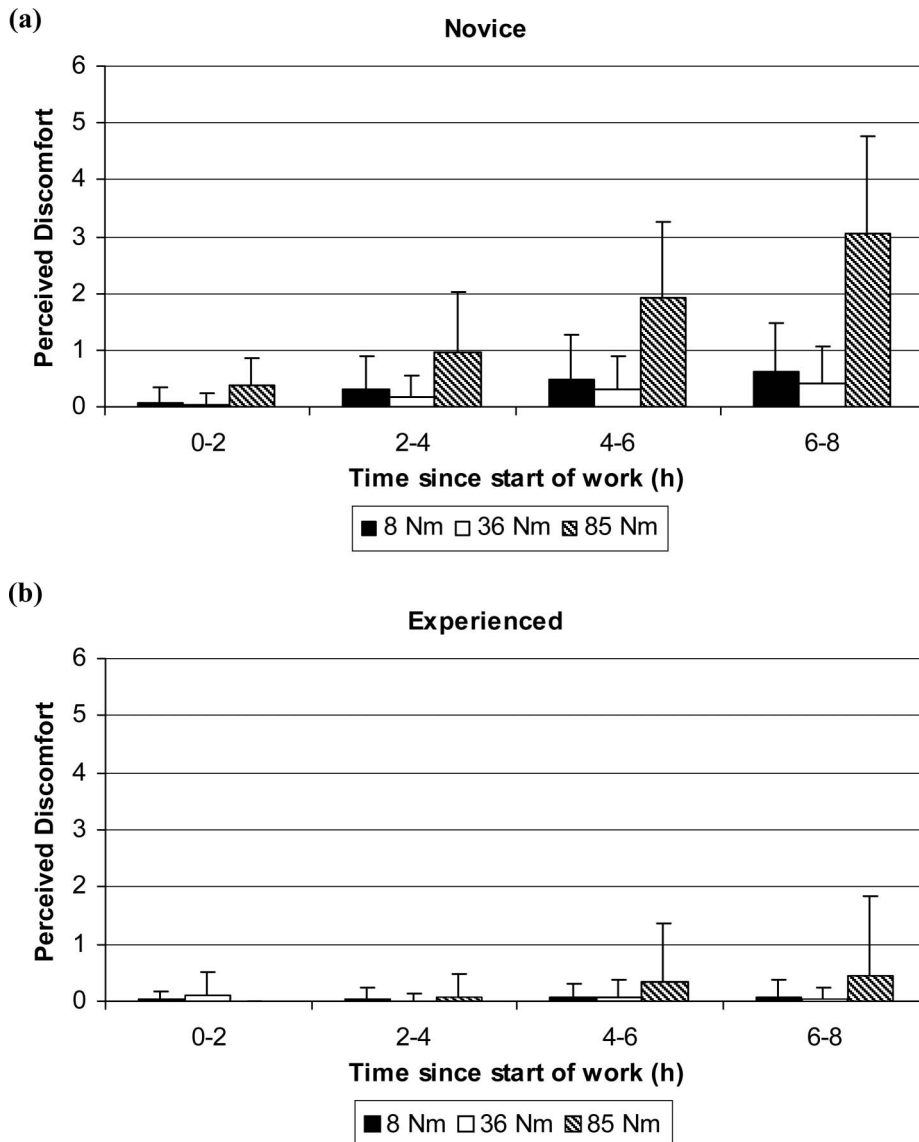


Figure 8. Interactive effect of moment and time on novice (a) and experienced (b) subjects' perceived discomfort. (Error bars represent standard deviation.)

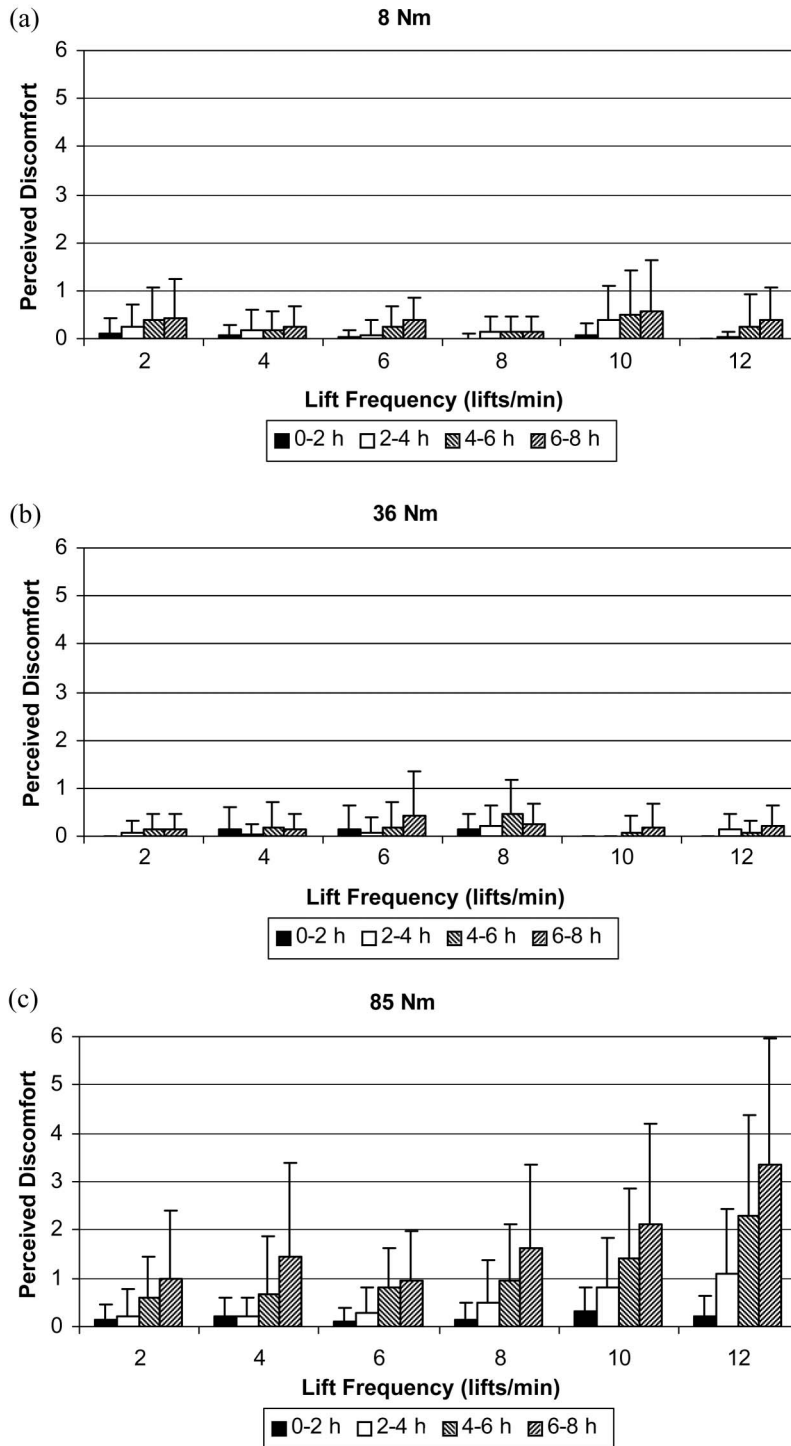


Figure 9. Interactive effect of lift frequency and time at different moment levels on perceived discomfort: (a) 8 Nm; (b) 36 Nm; (c) 85 Nm. (Error bars represent standard deviation.)

frequency increased. At the 85 Nm moment level, except for the first 2 h, there was a linear trend of increased discomfort for the rest of the day (over the 2–4, 4–6 and 6–8 h periods) as lift frequency increased. Moreover, as the day progressed, there was also a linear trend of increased discomfort within each of the six lift frequency conditions. The highest discomfort came from the highest lift frequency condition (12 lifts/min) after the last 2 h of the experiment.

The main and interactive effects of experimental factors on spinal loading have been published separately (Marras *et al.* 2006). Comparisons were made for factors that had significant effects on both perceived discomfort and spinal loading. The reported discomforts were generally unrelated to the loads experienced by the spine. For example, figure 10 shows spine compression as a function of moment exposure and experience. The 8 Nm condition resulted in statistically significant differences between the experience groups ($p=0.0008$). Comparing this spinal loading trend to the discomfort reports in figure 4, it is clear that subjects' perceptions of discomfort are dramatically different than the load imposed upon the spine. The figures indicate that compression increased monotonically with increasing moment exposure for both experienced and inexperienced subjects, whereas discomfort increased only under the 85 Nm exposure condition and only for the inexperienced subjects. Hence, this strong dependence on level of experience suggests that perceived discomfort reports are not representative of the biomechanically incurred spinal loading. The dissociation of discomfort and spinal loads is also manifested by the interactive effect of moment and time on AP shear force (figure 11). For the 8 Nm moment level, AP shear increased after the first 2 h of exposure. For the 36 Nm and 85 Nm moment conditions, AP shear did not significantly change throughout the day. This is different from the trends shown in figure 6 for discomfort, which shows increased discomfort for all moment levels as time of exposure increased, especially for the 85 Nm condition.

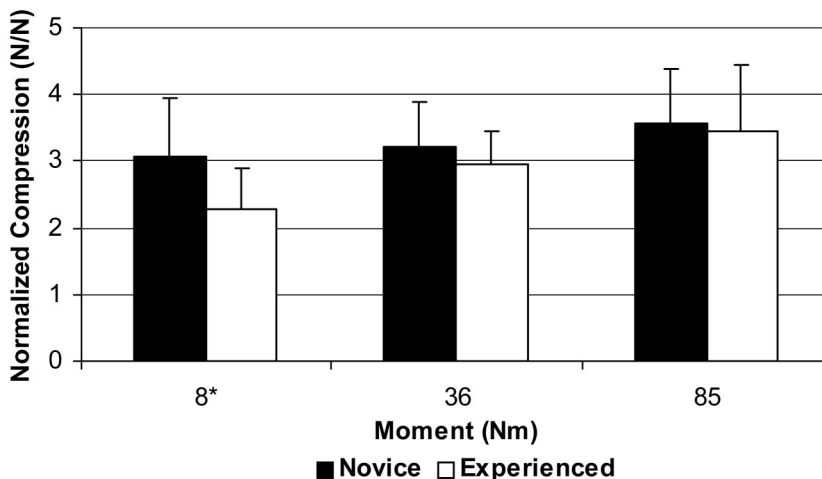


Figure 10. Interactive effect of moment and experience on compressive loading. *Indicates significant difference between novice and experienced subjects. N/N represents normalized to body weight. (Error bars represent standard deviation.)

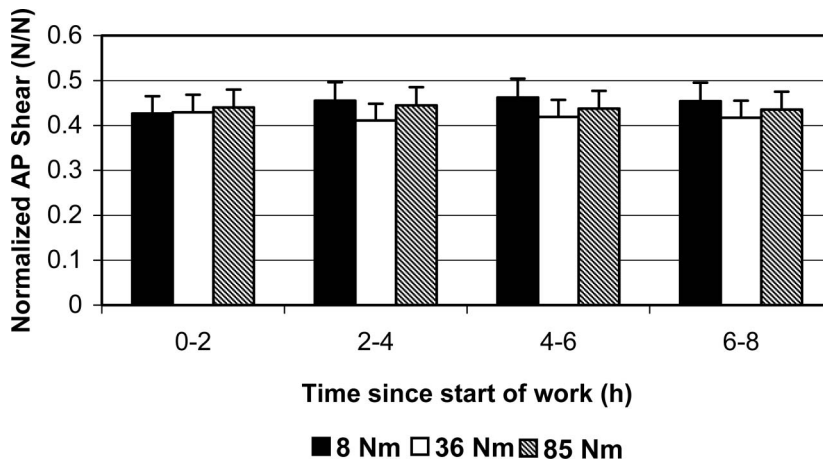


Figure 11. Interactive effect of moment and time on anterior-posterior (AP) shear. N/N represents normalized to body weight. (Error bars represent standard deviation.)

4. Discussion

In this experiment, discomfort information was collected from each subject every hour in an effort to determine which experimental factors influenced reporting of discomfort and to correlate the subject's perception of discomfort with the monitored spinal loading calculated via the EMG-assisted spine model. The findings from this study suggest that reporting of the perceived discomfort is influenced greatly by the lifting experience of the subject. Novice workers had reported much higher discomfort levels than their experienced counterparts and had very noticeable increases in perceived discomfort as the moment increased and as the day progressed. Experienced subjects, on the other hand, reported similarly low levels of discomfort, regardless of moment, lift frequency or duration of lift.

The constant, low-level perceived discomfort rating given by the experienced subjects can be explained in several ways. First, the findings may be attributable to a learned effect from their years of manual material handling experience. Despite the range of moments, lift frequencies and durations of lift, and although they may have exerted more of an effort in some conditions over others, the experimental conditions may have been very similar or even less strenuous than their everyday work conditions so that only low levels of discomfort were perceived. This learned effect might have trained the experienced subjects with fine-tuned motor programming, which is more efficient to perform these lifting tasks. The efficient motor pattern may help to reduce the biomechanical loading on the spine because the pattern of muscle activation shifts from simultaneous to sequential contraction (Parakkat 2005). In fact, compressive spine loading in experienced subjects was 13% lower on average than that in novice subjects as a result of minimized muscle coactivity. Second, these subjects were aware that they had been recruited because they had had at least 1 year of manual material handling experience as a condition of participation in the experiment. This knowledge may have biased the subjects' discomfort ratings because they may have associated reporting higher ratings as equivalent to complaints about the work conditions, which would have been atypical of their normal work attitude.

Despite the perceived discomfort trends of the experienced subjects, novices displayed very interesting discomfort rating in response to changes in the experimental factors. First, they only responded dramatically to the 85 Nm exposure condition (figure 4). Second, discomfort had significantly increased by the end of the workday. However, the reported discomfort increases throughout the day were also a function of the moment exposure condition. Novices lifting at 8 Nm reported increased discomfort from 0.07 to 0.63, at 36 Nm reported an increase from 0.04 to 0.40 and at 85 Nm reported an increase in discomfort from 0.37 to 3.06 (figure 8).

Based upon these findings, it is hypothesized that there is a threshold of moment, above which novice subjects perceive the task to be overly strenuous, regardless of the biomechanical implications. The 8 Nm and 36 Nm moments were acceptable to the novices, but 85 Nm was associated with high discomfort ratings. Once the acceptable threshold has been passed, there is an exaggerated increase in the discomfort ratings. Comparison of figures 4 and 10 indicates that at the 85 Nm moment level the compressive loads on the spine of experienced and novice subjects are about the same, while perceived discomfort rating is much higher in novices. This suggests that the relationship between discomfort and biomechanical estimates is different for the two groups. The discomfort threshold is lower in novices than in experienced subjects. It is conceivable that the acceptable threshold of moment in experienced subjects is somewhere higher than 85 Nm, which may trigger the increase of their perceived discomfort rating once passed. The reason why similar levels of biomechanical loading result in different discomfort rating is not known. While factors such as age, gender, subjects' belief and cultural background may all affect discomfort reporting, unfamiliarity with the task in novice subjects is more likely to yield a low acceptable threshold and cause their perception of discomfort to be higher. Further studies investigating the effect of experience on perceived discomfort should be conducted to elucidate this.

The findings from this study suggest that reported discomfort is not well correlated to biomechanical measurements. Increased spinal loads may show a very low discomfort rating. The discrepancy may be attributable to the fact that they are measuring different entities. Increased biomechanical loading applied to the spine may not necessarily cause discomfort immediately. But damage to tissue might have already occurred at the microscopic level. Moreover, discomfort as a subjective measure could be influenced by many factors other than physical work, such as psychosocial interactions, perceptions or personal preferences. As shown in this study, experience plays an important role in the threshold and reporting of perceived discomfort. The use of discomfort as a risk assessment tool will not be able to accurately represent the differences in physical requirements of the work. Hence, discomfort reports should be interpreted with caution when assessing the risk associated with a workplace.

There are several limitations to the study. First, the biomechanical model used to estimate spinal loading does not include deep lumbar muscles because they are not accessible through surface EMG. It is not known if the deep muscles functioned the same way for both the novice and experienced subjects. Second, data were collected from two subjects at the same time. They belonged to the same experience group, but were in sight of each other during the task. Although the subjects were asked to write down their discomforts separately, they were allowed to talk to each other during the experiment. It is possible that one of a pair of subjects may have talked about his/her discomfort, which could have affected the rating of the other subject.

5. Conclusions

The perception of discomfort is strongly influenced by experience level of an individual and minimally related to the loads experienced by the spine. Novices consistently reported higher discomfort levels than experienced subjects. The experienced subjects reported similar levels of discomfort for all levels of the experimental variables. Discomfort for novices increased significantly over the duration of the trial and once a certain acceptable threshold of moment was exceeded. These strong experience interactions indicate that caution must be used when interpreting studies that involve inexperienced subjects to apply the findings to experienced workers. In addition, discomfort should only be used as a supplement to objective measures, such as spinal loading, to assess the risk of low back pain.

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