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Trunk loading and expectation

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Much of the epidemiological literature has reported that there is a link between sudden unexpected load handling and the risk of a low back injury. However, few biomechanical studies have investigated the effect of this type of loading on trunk muscular response. An experiment was performed to test the hypothesis that sudden unexpected loads would create excessive forces upon the trunk due to the overcompensation of the trunk muscles, and to quantify the degree of overcompensation. Twelve male subjects were asked to hold a box in a static lift position while weights ranging from 2·27 to 9·07 kg were dropped into the box from a constant height. Under some conditions (expected) the subjects were permitted to observe the weight drop while under other conditions (unexpected) the subjects were deprived of visual and auditory cues during the weight drop. Several components of the trunk response were observed. Mean muscle forces for the unexpected condition exceeded those in the expected condition by nearly two-and-a-half times, and peak muscle forces in the unexpected condition were on average 70% greater. In addition, the unexpected condition produced longer periods of force exertion, as well as more rapid increases in trunk force development. Generally, it was found that during sudden unexpected loading the trunk response resembled an expected loading of twice the weight value. These findings may provide guidelines for work situations where unexpected loading conditions are common.

1. Introduction

There is evidence in the recent epidemiological literature suggesting that cognitive control of the neuromuscular system in a manual materials handler may mediate the risk of sustaining a low back disorder. Both Magora (1973) and Andersson (1981) concluded from epidemiological studies that workers exerting sudden unexpected maximal efforts are paticularly vulnerable to low back disorder. Sudden unexpected loading appears to cause the neuromuscular system to respond in a manner which is significantly different from sudden but expected load handling.

It is likely that sudden unexpected load handling causes the muscle control system of the trunk to over-respond in two ways to the load being controlled or handled. First, the magnitude of the trunk muscle forces may exceed the levels of force experienced under similar sudden, expected materials handling conditions. The mean and peak loading components of a muscle may be greater under unexpected conditions. Secondly, the temporal characteristics of trunk muscle loading may be expected to change as a function of expectation. Specifically, the onset rate of the muscle force exertion and the duration of elevated muscle force exertion levels are believed to exert greater total forces upon the trunk. Kroemer and Marras (1980, 1981) developed an empirical model of muscle force regulation and found that muscle force onset rate was linearly related to the magnitude of the intended force exertion. Thus, it would also be anticipated that under unexpected conditions the onset rate of the muscle force within the trunk would be much more rapid. This condition of sudden impulse loading could be much more destructive and increases the risk of low back disorder onset. A muscle force of longer duration also indicates that the spine is loaded for a longer period suggesting increased strain within the trunk.

In this study, the activity of the trunk muscles is of primary concern in the evaluation of trunk loading. This is due to the fact that the trunk muscles contribute a far greater portion of the spine loading compared to the external load being handled. Biomechanically, the trunk muscles are at a mechanical disadvantage compared to the external load. This disadvantage occurs because the moment arm between the muscles and the spine is very short compared with the moment arm between the external load and the spine. Thus, under normal lifting conditions very large trunk muscle forces are required to handle the external load. Furthermore, it is the large trunk muscle forces which are primarily responsible for loading the spine and causing a low back disorder. It is believed that under sudden unexpected loading the trunk muscles exert even larger amounts of force and overload the spine. It may be the case that during unexpected conditions the trunk muscles contract to a maximum regardless of the magnitude of the external load. This would make any unexpected load dangerous.

Knowledge of the manner in which the trunk responds to unexpected loading may be valuable for the design of the manual materials handling environment. If the manner in which the trunk is overloaded due to unexpected loading is understood, it may be possible to specify load handling limits so the load on the spine, even during sudden unexpected loading, does not exceed an acceptable level. This information could then be applied to unstable load handling situations, such as with the handling of liquids, or when handling any unstable load where it is common to experience unexpected or shifting loads.

Similarly, the tendency to over-respond to unexpected events may be related to injuries during slips and falls in the workplace. Troup *et al.* (1981) suggested that slipping accidents were often associated with sudden jerking or twisting actions. The risk of low back injury during slips and falls has been well documented by Manning and Shannon (1981). The sudden unexpected nature of a fall may cause the trunk muscles to over-respond and overload the trunk. This stress, coupled with the impact of the fall, may be responsible for the increased risk of injury observed in falls.

The objective of this study was to determine the degree to which the spine is overloaded during unexpected loading. In order to quantify this over-response, the following components of the trunk muscle action were investigated: (1) the average relative magnitude of muscle force, (2) the peak force exerted by the muscle, (3) the onset of muscle force development during the exertion, and (4) the time duration of the muscle force. These components were investigated as a function of both sudden expected and sudden unexpected load handling.

2. Method

2.1. *Subjects*

Subjects in this experiment consisted of 12 male volunteers ages 21 to 32 years (mean 26 years). All subjects were in good physical shape and none had a history of low back disorder. Mean subject height was 182·04 cm and mean weight was 79·74 kg. All the subjects were recruited from the Ohio State University campus. Subjects were briefed as to the nature of the experimental conditions but were not told the experimental hypothesis. The use of subjects was approved by the University Human Subjects Committee and all subjects signed consent forms approved by the committee. No rewards or inducements were provided in exchange for subject participation.

2.2. *Design*

Independent variables in this experiment consisted of the expectation condition and the weight of the load which was handled. Expectation conditions comprised expected or unexpected loadings of the trunk. Under each condition, a load was suddenly imposed upon the subject by dropping a weight into a box which the subject was holding. Under the expected condition, the subject was allowed to view the weight dropping into the box. Under unexpected conditions the subject was deprived of visual or auditory cues indicating when the weight would be dropped into the box. Weight conditions consisted of four levels: 2·27, 4·54, 6·80 and 9·07 kg (5, 10, 15 and 20 lb).

A repeated measures design was used with the expectation and weight level variables completely crossed. Each subject was tested under each expectation–weight level combination. The sequence of experimental weight conditions was assigned randomly so that the carry-over effects could be controlled.

The dependent variables consisted of the electromyographic (EMG) activity of the trunk muscles. These muscles include the right latissimus dorsi (LATR), left latissimus dorsi (LATL), right erector spinae (ERSR), left erector spinae (ERSL), right rectus abdominus (RCAR) and left rectus abdominus (RCAL). These muscles represent the main supporting structures of the trunk accessible by surface EMG. Studies by Schultz and Andersson (1981) and Marras *et al.* (1984) have employed a transverse-plane analysis to study the trunk muscles which are employed during lifting actions. These studies have shown that the latissimus dorsi, erector spinae and rectus abdominus muscles all play an active role in supporting the trunk during lifting. These muscles are also primarily responsible for loading the trunk. The EMG activity was 'integrated' (RMS integration) and normalized so that the signal represented the relative force produced by the muscle. The activity of these muscles was observed throughout the experimental conditions as well as during static holding and maximum effort exertions. The static and maximum exertions were recorded for calibration purposes.

2.3. *Apparatus*

A pipework frame was constructed to position a pulley above the box held by the subject. A rope attached to the weight was run through the pulley and secured to the reference frame (figure 1).

The subject held a 30·5 × 30·5 × 22·9 cm box to catch the falling weight. This box was provided with two handles perpendicular to the floor, positioned in the centre of the outside portions of the box. A microswitch, located at the bottom of the box, indicated when the load had contacted the box.

The weights consisted of lead shot sealed in nylon bags. This provided a load which would not bounce off the bottom of the box during sudden loading. These loads were dropped from a height of 83·8 cm above the bottom of the box.

The EMG signals were recorded through small surface electrodes placed upon the muscle of interest. These electrodes were connected to small preamplifiers mounted on a belt worn by the subject. This arrangement ensured a relatively noise-free signal by keeping the electrode leads short. The preamplifiers were connected to main EMG amplifiers via coaxial cable. These amplifiers amplified and filtered the signals which were then passed through a switch box and 'integrators' (time constant was 0·2 s) which converted the EMG signal into relative force.

The six EMG signals and the microswitch signal were monitored with an ISAAC 2000 data acquisition system. (This device digitally monitored the signals and stored the data in its buffer.) The data acquisition system was interfaced with an IBM Personal

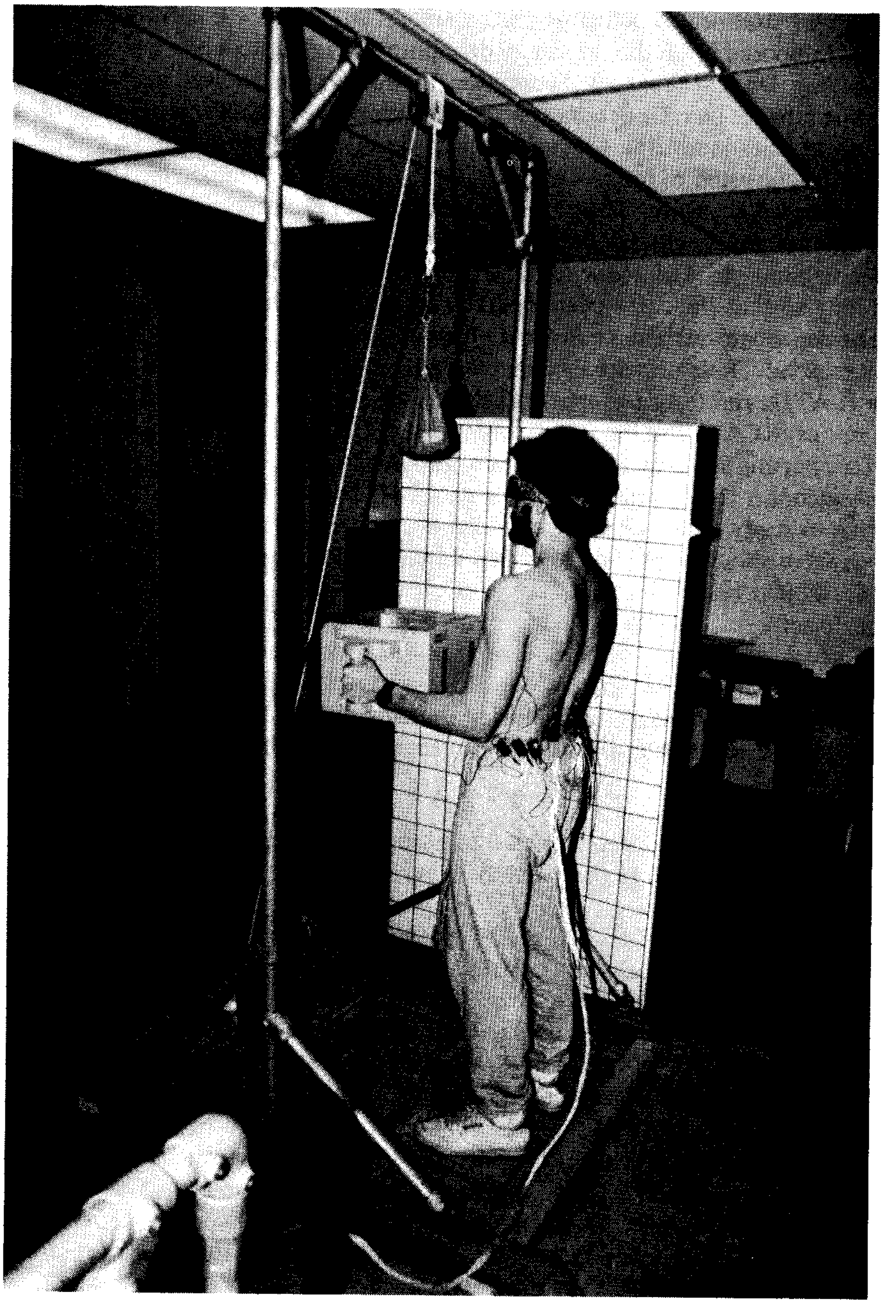

Figure 1. A subject within the experimental reference frame during an unexpected condition.

Computer which converted the signals into calibrated form and computed statistics on the signals. Further inferential statistical analysis was performed on the University main-frame computer.

2.4. *Procedure*

Subjects were permitted a warm-up period to allow stretching and loosening of their muscles. They were instructed in particular to stretch their back muscles. Second, the EMG instrumentation was attached to the subject. The six pairs of surface electrodes were applied to muscles of interest at standard muscle sites as described by Basmajian (1978). Electrode conductivity was checked (with an ohmmeter) and electrode location was verified through functional muscle testing.

When the subject had warmed up and been instrumented the experimental session began. This session consisted of three elements. First, the maximum activity over a 3-second exertion of the trunk muscles was recorded. This was accomplished by strapping the subject into a back dynamometer apparatus to monitor the maximal static torque the subject could exert with his trunk. This apparatus is described in Marras *et al.* (1984). Static sagittally symmetric flexion and extension was monitored while the subject was in the upright standing position. The EMG activity of the six trunk muscles as well as trunk torque was monitored throughout these exertions.

Second, the EMG activity required to hold the box statically under each weight conditions was recorded. The subject was asked to assume the experimental position. This position required the load to be positioned at a distance of 44·5 cm from the spine of the subject. Each experimental weight was held in this position for a 3-second period. All static holds in this position were well within the action limit of lifting as defined by NIOSH (1981).

Third, the sudden unexpected and expected experimental trials were run. During these exertions the subject held the box in the experimental position just described but now the experimental weights were dropped from a constant height (83·6 cm) into the box. Under the unexpected condition, the subject was blindfolded and wore ear plugs. A masking noise was also generated during these unexpected trials. In this manner subject knowledge of exactly when the load was dropped was eliminated. Under the expected conditions, the subject was permitted to view the weight drop. During the expected conditions, the subjects were asked not to anticipate the weight drop by elevating the box just before impact. Subjects were instructed to maintain the same static position. This procedure helped minimize any pre-tensing of the muscles.

Weight levels were assigned randomly and each subject was tested under each weight–expectation condition once to help control for learning effects. Subjects were allowed at least two minutes rest between experimental trials.

2.5. *Data treatment*

All the data used in the statistical analyses were derived from the raw data via software programs developed in the laboratory. This software reviewed the raw data file and computed several factors. First, the point at which each EMG signal increased over its resting level and the point at which each signal returned to the resting level were defined. The difference between these two points was defined as the time duration of muscle force. Secondly the maximum instantaneous signal, within this period of muscle force duration was noted. This values was defined as the peak force developed during the exertion. Thirdly, the average activity during the duration period of the signal just expected condition. The increases in peak activity during the unexpected conditions ranged from 1·2 to 3 times that of the expected conditions, with an average increase of 1·7 times. The nature of these differences is shown in figure 4. As expected, the peak force activity also displayed statistically significant responses to the weight condition. Five of the muscles (all except RCAL) showed significant increases as the weight condition increased. These results are shown in figure 5 for each muscle group. This figure shows the average activity of the right and left muscles for each muscle group.

Third, the rate of onset of muscular force development was evaluated. The rate of onset indicates how rapidly the trunk is loaded during an exertion and may be related

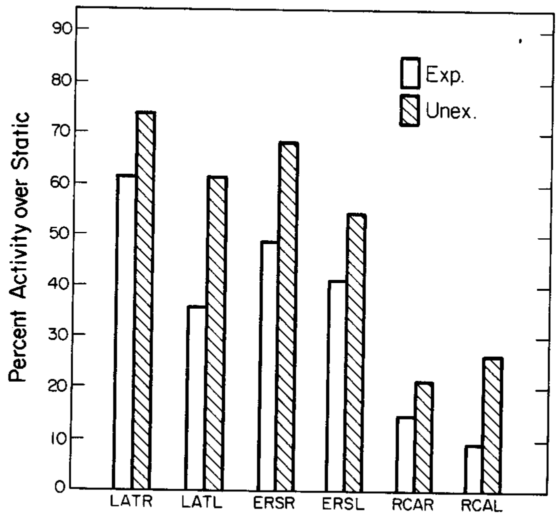

Figure 4. Peak (maximum) muscle activity during expected and unexpected loading.

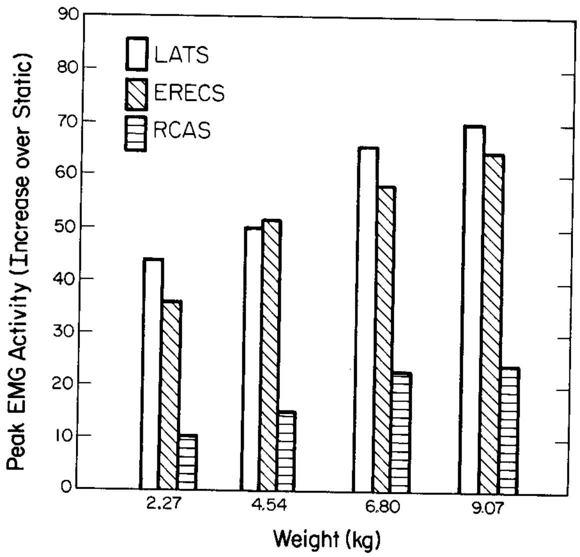

Figure 5. Peak (maximum) muscle activity as a function of load weight.

to the risk of back injury. This variable demonstrated a significant response in all muscles to the expectation condition and is also summarized in the table. Greater rates of onset were observed for unexpected condition. The greatest differences were seen in the rectus abdominus muscles. The magnitude of these differences is indicated in figure 6.

Finally, the duration of force exertion required for the muscles to control the load was investigated. Significant effects of both expectation ($F(1,88)=6{\cdot}52$, $P \leqslant 0{\cdot}05$) and weight ($F(3,88)=19{\cdot}77$, $P \leqslant 0{\cdot}05$) were observed. Under the unexpected conditions the muscle force duration increased by an average of 12%. When the weight of the load was increased the duration of the muscle force also increased by about 0·09 s for each increase of 2·27 kg in load weight. The magnitude of these differences is shown in figure 7.

4. Discussion

These results stress the importance of dynamic interpretations in biomechanical models. Since most models used for occupational workplace design are static and consider only the mean muscle force activity, it appears that these models may

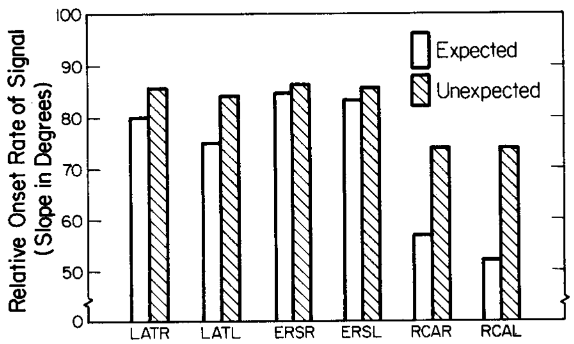

Figure 6. Relative onset rate of muscle signals during expected and unexpected loading.

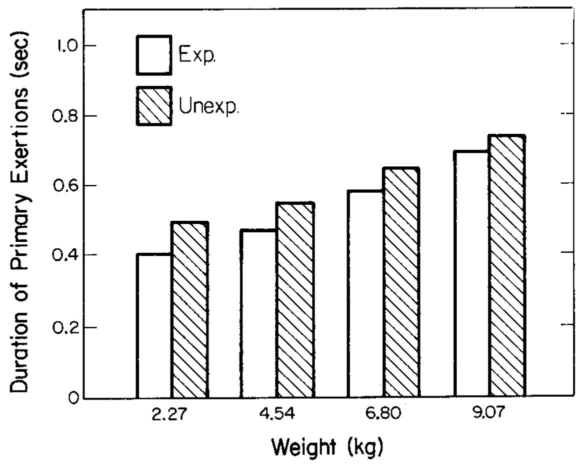

Figure 7. Elevated muscle signal duration during experimental conditions.

underestimate the loading due to dynamic events. For example, when the average trunk muscle responses (for all muscles) under static holding conditions were compared with the responses under sudden loading conditions significant differences were nofed. Expected sudden loading conditions increased average trunk muscle forces by about 10% over static conditions. During sudden unexpected conditions this increase in average loading for all muscles was over 14% above static conditions of the same weight. More dramatic differences were seen in peak muscle responses. Under sudden expected conditions the average increase over static peak loading was over 35%. However, the largest increase in peak loading over static was seen under sudden unexpected conditions, whereas the average peak response increase over static conditions was over 50% for all muscles. Hence, it is apparent that dynamic models of trunk loading are desperately needed and these models must take into account the synergistic effects of the various phases of muscle loading, such as peak loading.

The results of this study indicate that there are differences in average, peak, onset rate, and duration of the muscular response between expected and unexpected loading conditions. In each case the unexpected condition elicited trunk muscle reactions which result in greater loadings of the trunk. The magnitude of the unexpected loads averaged 1·7 times that of expected loadings for the peak component of the muscle force, and 2·4 times the expected loading for the mean component of the muscle force.

These findings suggest that there is an over-reaction of trunk loading that occurs when sudden unexpected loads are imposed upon the trunk during manual materials

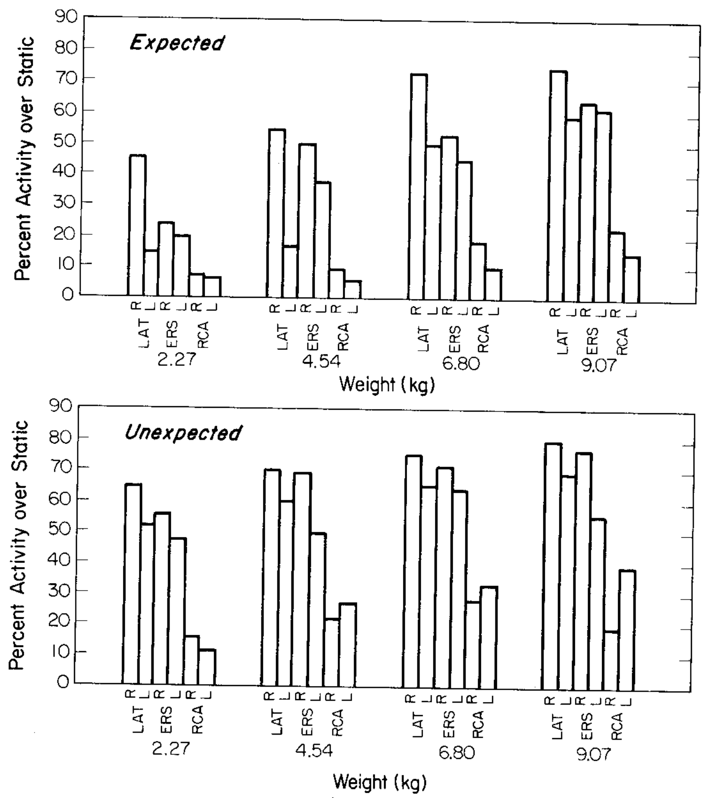

Figure 8. Peak components of all muscle activities under experimental conditions.

handling. The expected and unexpected reactions were determined for each muscle as a function of load weight. Peak components of muscular force were significantly affected independently by both expectation and weight for all muscle reactions compared. This comparison is shown in figure 8, which indicates that the effect of unexpected loading makes the muscles respond as if the weight of an expected load were doubled.

These findings indicate that during unexpected loading conditions the trunk muscles do not simply produce maximal force under all conditions, but respond selectively to different weights. However, they also over-react by about a factor of two compared with expected loading.

The rate of muscular force onset is also exaggerated in an unexpected exertion. This may lead to a particularly dangerous situation since greater trunk forces are occurring very rapidly. This suggests that the occurrence of great acceleration or jerk forces may lead to a traumatic low back disorder. These differences in force onset are particularly severe in the abdominal muscles, which would cause a forward moment in the spine.

The data presented in this study indicate that differences in response to expected and unexpected loading are quantifiable over a small range of loading weights. In future research this range could be expanded to determine whether relations found here apply throughout the range of safe manual materials handling. This information could lead to guidelines for safe loading limits applicable to work situations where unexpected loading is common, such as in unstable load handling situations. This information may also provide a useful starting point for a biomechanical model which describes the congnitive-biasing effects of expectation upon the musculo-skeletal system. Further refinements of such a model could quantify the risks associated with unexpected events such as sudden load handling, slips and falls.

Dans de nombreuses études épidémiologiques on fait état d'une relation entre le brusque maniement manuel d'une charge inattendue et le risque d'une lésion lombaire. Cependant peu de recherches bio-mécaniques ont étudié les effets de ce type de charge sur la réponse musculaire du tronc. Une expérience a été effectuée afin de tester l'hypothèse que de brusques charges inattendues produisent des forces excessives dans le tronc dues à une surcompensation des muscles du tronc et afin de quantifier, s'il y a lieu, cette surcompensation. Douze sujets hommes devaient tenir une caisse en position de levage statique tandis que l'on faisait tomber dans la caisse, depuis une hauteur constante, des poids allant de 2,27 à 9,07 kg. Dans certaines conditions ('attendues') les sujets pouvaient percevoir la chute des poids, alors que dans d'autres ('inattendues') ils ne disposaient pas d'indices visuels ou auditifs de la chute. Plusieurs composantes de la réponse du tronc one été observées. Les forces musculaires moyennes dans la condition 'inattendue' dépassaient de presque deux fois et demie celles de la condition 'inattendu'; les forces musculaires de crête augmentaient, en moyenne de 70% dans la condition 'attendue'. En outre, cette dernière condition entraînait de plus longues périodes d'exertion de la force, ainsi que des accroissements plus rapides dans mobilisation des forces du tronc. En général, on a trouvé que durant un accroissement brusque d'une charge inexpectée, la réponse du tronc était comparable à deux fois celle qui se produit avec une charge expectée. Ces résultats pourraient fournir des indications utiles pour les situations de travail dans lesquelles le soulèvement de charges à poids inattendu est courant.

Eine Vielzahl der epidemiologischen Literatur berichtet, daß es eine Verbindung zwischen plötzlicher unerwarteter Lastenhandhabung und dem Risiko einer Verletzung des unteren Rückenbereiches gibt. Wie auch immer, wenige biomechanische Studien haben des Einfluß dieses Typs von Last auf die Reaktion der Rückenmuskulatur untersucht. Es wurde ein Experiment ausgeführt, um die Hypothese zu testen, daß plötzliche unerwartete Lasten sehr hohe Kräfte im Rücken bedingt durch die Überkompensation der Rückenmuskulatur hervorrufen und um den Grad der Überkompensation zu quantifizieren. Zwölf männliche Versuchspersonen wurden aufgegordert, eine Kiste in einer statischen Hebeposition zu halten, während

Gewichte in dem Bereich von 2·27 bis 9·07 kg aus einer konstanten Höhe in die Kiste fallen gelassen wurden. Unter einigen Konditionen (erwarteten) war es den Versuchspersonen gestattet, den Fall des Gewichtes zu beobachten, während unter anderen Konditionen (unerwarteten) es ausgeschlossen wurde, daß die Versuchspersonen den Fall des Gewichtes mit den Augen und Ohren registrierten. Einige Komponenten der Reaktion des Rückens wurden beobachtet. Die Mittelwerte der Muskelkräfte für die unerwartete Kondition überstiegen die der erwarteten Kondition um das $2\frac{1}{2}$ fache und die Spitzenwerte der Kräfte waren im Durchschnitt für die unerwartete Kondition um 70% größer. Außerdem rief die unerwartete Kondition längere Perioden der Kraftausübung hervor, genauso wie rapide Anstiege der Kraftentwicklung des Rückens. Allgemein wurde festgestellt, daß während dem Auftreten plötzlicher unerwarteter Last die Rückenreaktion dem zweifachen Wert des Gewichts bei erwarteter Last ähnelt. Diese Erkenntnisse mögen Richtlinien für Arbeitssituationen darstellen, bei denen das Auftreten von unerwarteter Last üblich ist.

多くの疫学文献は予期しない荷重取扱と腰部損傷の危険に関連性があると報告している。しかしながら，この種の負担が体幹筋反応に及ぼす影響を調査した生体力学的研究は殆ど見られない。予期せぬ荷重が体幹筋の過剰補償のために体幹に過大な力を加えるという仮説を検定し，その過剰補償の程度を数量化するために実験を実施した。12名の男性被験者は 2.27 から 9.07 kgまでの重量が一定の高さから箱に落される間その箱を静的持ち上げ姿勢で保持していることを要求された。ある（予期）状態下では被験者は荷重が落下するの見ることを許されたが，他の（予期せぬ）状態下では荷重落下中の視覚・聴覚的手がかりが与えられなかった。体幹筋反応の幾つかの成分が見られた。予期せぬ状態下での平均筋力は予期状態下でのそれの 2.5 倍近くあり，予期せぬ状態下での最大筋力は平均して70%大きかった。更に，予期せぬ状態下での力の持続は長く，体幹筋力の増大も速かった。一般に，予期せぬ荷重負担中での体幹筋反応が 2 倍の荷重の負担時に類似していることが分かった。これらの知見は予期せぬ荷重負担が普通である作業状況に対する指針を与えるものと思われる。

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