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Loads on the lumbar spine during a work capacity assessment test

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Abstract. Many clinicians and employers utilise work-related assessment tools for the purposes of identifying whether or not the performance of a specific job exposes an individual to a heightened risk of developing a low back injury. However, research has shown that some of these tools have not been assessed for validity or reliability, and thus may not accurately assess the risk associated with a particular activity. An example of a test employed by some Australian private industries is the Work Capacity Assessment Test, which is a procedure that is commonly used to screen potential employees and evaluate those workers returning to the workplace following injury. This research was designed to simulate the lifting component of the Work Capacity Assessment Test and involved a series of lifts ranging from 2.5 kg to 22.5 kg. Six subjects performed this task, whilst being assessed using two-dimensional videography and surface electromyography. The two-dimensional kinematic data were input into the 4D WATBAK software to quantify the compression forces acting between L4 and L5 during each performance. Results of this study showed that spinal compression and paraspinal muscle activity increased incrementally from the 2.5 kg lift to the 22.5 kg lift, whilst abdominal muscle activity also increased across the lifts. This study demonstrated that lifting masses of 22.5 kg or more can produce loads on the spine that are considered potentially hazardous, when compared to safe lifting guidelines, and indicated that there is a clear concern for the use of such lifting tasks in the evaluation of workers following injury.

Keywords: Work-related assessment, workplace assessment, lifting, manual material handling, vertebral stresses

1. Introduction

It has been evident for some time that low back disorders, such as low back pain, constitute a major public and occupational health problem in highly-developed and industrialised societies [10,28,32,50]. Previous research, has reported that between 15 and 40 percent of the general population in many countries are affected by low back pain during any given year [40], whilst as many as 80 percent of the population will experience the disorder at least once throughout their lifetime [4, 9,26,35,51]. In spite of the large health and economic costs that are generated by low back pain [7,28], it is interesting to note that the aetiology of 75 percent of cases is largely ambiguous [40]. However, as a result of extensive epidemiological research, it has been established that the performance of work-related tasks that involve lifting or lowering may predispose an individual to a greater risk of developing low back pain [6, 45]. According to the findings of Marras et al. [32] and Chaffin and Park [2], the risk of developing an injury in the lower back can be increased by up to eight times during the performance of a manual lifting task, when compared to other non-lifting activities. An improved awareness and appreciation for the potential risks associated with manual lifting tasks has contributed to the introduction of preventative measures, such as correct lifting technique training, in an effort to reduce the incidents of low back complaints within the working environment [46,47]. Although the effectiveness of these methods in reducing the number of low back injuries has not been established, it is interesting to note that these injuries still account for about 80 percent

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of all of the injuries sustained during manual handling tasks [39].

Over the past few decades, many clinicians and employers have developed and utilised work-related assessment tools for the purpose of identifying whether or not the performance of a particular job predisposes an individual to an elevated risk of developing a low back disorder [14,30,42,48]. In many cases, the work-related assessment will involve a direct observation of the employee or potential employee performing a simulation of the tasks that they are likely to perform as part of their normal work duties [18,19,42]. As a consequence, many of the tests employed within industrial settings and occupational environments such as hospitals and aged care facilities, involve some form of manual lifting component as a method of assessing the physical capabilities of potential employees and previously injured workers, despite the established risk [15, 18]. According to previous research, many organisations within Australia are currently employing these tools for the purposes of screening potential employees and for assessing an individual's physical capacity to return to the workplace following injury [19,48]. Although some of these tests have been found to provide both valid and reliable results (e.g. [27,41,48]), research suggests that there are still many assessments that have not been questioned for reliability [17] or validity [18]. Hence, this may have an impact on their efficacy for clinical, legal or insurance purposes.

An example of such a test that is currently used within some Australian private industries is what is termed the Work Capacity Assessment Test. Although this test has many components, one task requires the subject to lift a box (containing weights) from the floor onto a bench and then return it to the floor again. Following the completion of this initial task, additional weights (mass) are added to the box sequentially until a mass of 25 kg is reached [15,18,19]. Prior to performing these lifts, the subjects are given no technical instruction as to how to lift the box safely and no considerations are made for differences in subject age, gender or anthropometry. In addition to this, the task performed by the subject is standardised and therefore may not simulate the specific demands of the different roles played by different employees within an industrial setting.

It was the purpose of this research to simulate the lifting component of the work capacity assessment test in order to examine the lumbar compression forces that may be developed during the performance of this task. This research has value for both industry and academia in understanding lifting assessments in functional capacity evaluations and their potential role in injury development.

2. Methodology

2.1. Subjects

The sample group of this investigation comprised six individuals (demographic information included in Table 1), all of which expressed interest in the study and volunteered to perform the Work Capacity Assessment Test. All six subjects were recruited from different occupational groups and were considered to be similar to the types of people that would be expected to perform similar functional capacity assessments within the workplace. The Divisional Ethics Committee for Health Sciences at the University of South Australia approved the experimental protocol of this investigation.

2.2. Task

The experiment performed by the six subjects comprised five lifting tasks, in which they were asked to raise a plastic box (height × width × depth = 0.29 × 0.365 × 0.365 m) with a known mass from the floor to a bench top (Fig. 1). The subjects started in the same position each time (0.84 m from the box), but were then free to move forward and position themselves appropriately to lift the box using its handles, which were 0.26 m above the floor. Once the box had been raised from the floor, the subjects were required to place it onto a wooden bench (height × width × depth = 0.695 × 0.41 × 0.41 m), which was positioned to their left at a distance of 0.32 m. Upon completion of the initial lift of 2.5 kg, the subjects were informed that the mass of the box would be increased to 7.5 kg through the addition of a single 5 kg gym weight and that they would be required to perform the same task for a second time. Similarly, the mass of the box was increased by a further 5 kg prior to each subsequent lift until the subjects withdrew or a maximum load of 22.5 kg was attained. The added weights were placed onto a centrally located rod within the box, which helped to distribute the weights evenly and prevent them from moving throughout the performance of the task. As the task was designed to closely replicate the Work Capacity Assessment Test, the lifting technique employed by the subjects was self-selected (i.e. no instruction was given). Similarly, the individual performances of the subjects were not governed by any temporal demands, as the pace at which the tasks were performed was not regulated in any way by the researchers. Although the subjects were free to choose their own preferred lifting technique, it is interesting to note that all six subjects elected to use the leg lift (also known as the squat lift) in preference to back lift (stoop lift).

Table 1
The gender, age, mass and height of the six participants

	Subject characteristics							
	Male			Mean (SD)	Female			Mean (SD)
Subject	1	3	5		2	4	6	
Age (yrs)	40	40	30	36.7 (5.8)	38	39	39	38.7 (0.6)
Mass (kg)	70.6	91.4	84.4	82.1 (10.6)	59.2	51	55.4	55.2 (4.1)
Height (m)	1.71	1.83	1.78	1.8 (0.1)	1.71	1.59	1.64	1.7 (0.1)

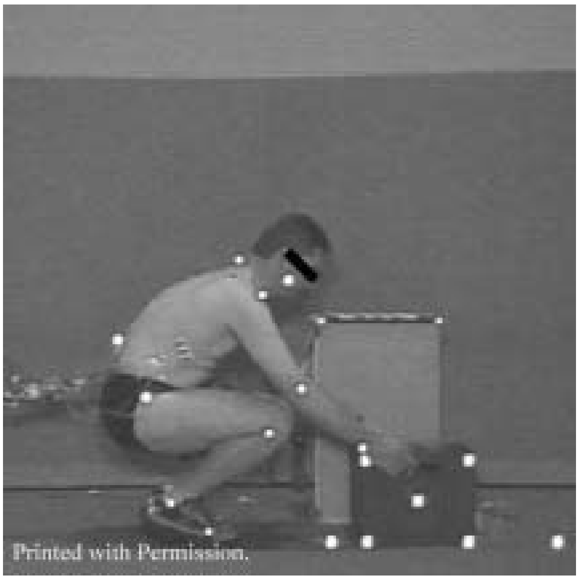

Fig. 1. Shows the experimental layout and an example of the free lifting technique used by the subjects.

2.3. Data collection

2.3.1. Two-dimensional videography

Both male and female subjects were required to wear flat-soled shoes and minimal clothing, in order to facilitate the accurate depiction of several specific anatomical landmarks using reflective markers. A single reflective marker was placed on the lateral aspect of the subjects' right shoe, in an attempt to approximate the location of the fifth metatarsophalangeal joint. The additional nine reflective markers were positioned on the right side of the subjects' bodies on the lateral malleolus; the lateral epicondyle of the femur; the greater trochanter; the L4/L5 intervertebral joint; the spinous process of T1; the temporomandibular joint; the lateral border of the acromion; the lateral epicondyle of the humerus; and the ulnar styloid. Two additional markers were placed on the left and right edges of the bench top at a distance of 0.39 m apart, whilst another was positioned on the estimated centre of mass of the box. For the purposes of this investigation, the box's centre of mass was defined as the intersection point of two diagonal lines that were drawn on the facing surface, from both its upper corners. The reflective markers were illuminated by two HE-888 Universal 500 W spotlights (Security Instruments, Maryland, USA), which were situated 0.37 m apart and placed at a horizontal distance of 0.95 m from the camera's lens and at a vertical height of 1.21 m.

Each trial was filmed using a Panasonic SVHS NV-MS5 video camera (Matsushita Electric Industrial Co Ltd., Kadoma City, Osaka, Japan), which was operating at 50 Hz and had shutter speed and iris settings 1/500th of a second and Open +2, respectively. The camera was positioned perpendicularly to the plane of motion at a horizontal distance of 5.47 m from the centre of the force platform and at a vertical height of 0.87 m, as measured from the centre of the camera lens.

2.3.2. Electromyography

Surface electromyography was used to record EMGs from the paraspinal and abdominal muscles to aid in the explanation of any changes that may occur in the lumbar compressive force. An Amlab II EMG System (Amlab International, Inc., Lane Cove, NSW, AU) was used to record EMGs during the lifting tasks. Electromyographic signals were detected from each muscle by two Ag/AgCl pre-gelled surface electrodes (Red Dot 2258-3, 3M, Ontario, CA), which had a detection surface of 1 cm (gelled) and an overall diameter of 3 cm. The electrodes were positioned with a centre-to-centre distance of 2 cm, which was achieved by overlapping the adhesive edges of the electrodes. Each pair of electrodes was attached to a differential amplifier (gain × 1000, input impedance $= 500$ MΩ, common mode rejection ratio $>$110 dB, noise $=<2$ μV) with a bandpass frequency of 10–480 Hz and a notch filter of 49–52 Hz. The amplifier was connected to a PC via a 12-bit analog-to-digital expansion board and the signal from each muscle was sampled at 1000 Hz using the Amlab II (Build 19.8) acquisition software (Amlab International, Inc., Lane Cove, NSW, AU).

Recording electrodes were positioned bilaterally over the erector spinae at the level of the fourth lumbar vertebra (L4), with the reference electrodes located over spinous processes. Bilateral activity of the rectus abdominis was detected by placing the electrodes a distance of 2 cm lateral to the midline of the body at the level of the anterior superior iliac spines, with the reference electrodes placed over the ribs. An imaginary line between the recording electrodes in each given pair was orientated parallel to the approximate orientation of the underlying muscle fibres. Prior to the positioning of the electrodes, the skin was shaved and cleaned thoroughly with an alcohol wipe to reduce impedance at the electrode/skin interface.

Data acquisition from the video camera and the EMG system were synchronised using an event and video control unit (Peak Performance Technologies Inc., Englewood, CO, USA).

2.4. *Data analysis*

2.4.1. *Two-dimensional kinematics*

The video footage for each subject was digitised using Peak Motus 2000 (Peak Performance Technologies Inc., Englewood, CO, USA) to obtain a complete set of kinematic data.

For the purposes of digitisation and the calculation of two-dimensional kinematic data, a linked-segment model was created within the Peak Motus 2000 software. Within this model, angles were calculated from the right horizontal for the lower leg; the upper leg; the pelvis; the trunk; the head; the upper arm; and the forearm. In addition to this, seven virtual points were positioned on each of the links at the calculated segment centre of mass, whilst an eighth virtual point was included to represent the whole body centre of mass. The relative positioning of each of these virtual points was calculated using the anthropometric data derived by Dempster in 1955, as presented by Winter [54]. Following the digitisation procedure, a quintic spline function [55] was applied to the raw coordinates in order to smooth the data and calculate kinematic quantities.

2.4.2. *Lumbar compression forces*

The resultant kinematic data were input into the 4D WATBAK modelling software (University of Waterloo, Ontario, CA), so that the magnitude of the L4/L5 compression force could be quantified. In order to calculate the spinal compression forces, the kinematic data corresponding to an individual field of the video footage was input into the 4D WATBAK software, which calculated the spinal loads associated with this component of the performance. Although it would have been desirable to obtain an estimate of the spinal loads for each visual field of the lifting task ($\overline{X} = 102 \pm 28$ fields), this was considered to be excessively time consuming, as it was only possible, using 4D WATBAK, to calculate the spinal loads for one field at a time. Consequently, the compression forces were quantified at five different positions over the duration of each lifting performance. As previous research has indicated the peak spinal compression force typically occurs within the first 150–200 ms of the lift [13], the first sample was taken at the time that the load was first displaced in a vertical direction. The four subsequent samples were taken at evenly-spaced intervals across the first two thirds of the lift and consequently coincided with 17%, 33%, 50% and 66% of the lifting performance. As the duration of each lifting task tended to differ between the subjects, the standardisation of such sample times was considered to be important in ensuring that the results obtained for each subject could be compared.

Table 2
The peak L4/L5 compression force for all subjects during the five different lifts. In each of the lifts, the peak compression force was recorded approximately 0.04 seconds after the box was first displaced from the floor

Subject/Lift	Peak L4/L5 compression force (N)				
	2.5 kg	7.5 kg	12.5 kg	17.5 kg	22.5 kg
1	2097.8	2460.8	2985.3	3362.0	3758.2
2	1708.3	2219.8	2651.9	3142.1	3499.1
3	3005.7	3637.4	4248.2	4788.7	5316.5
4	1378.3	1821.3	2300.7	2794.5	3184.9
5	2588.5	3017.6	3463.9	3879.1	4303.1
6	1469.3	1923.8	2472.9	2908.8	3290.2
Mean	2041.3	2513.5	3020.5	3479.2	3892.0
SD	649.7	697.6	729.2	747.8	804.1

Table 3
The recommended safe lifting limits (lumbar disc compression force expressed in Newtons) from Jäger and Luttman [20]. The limits identified with an asterisk (*) are those values that are applicable to the subjects of this study

Age (Yrs)	Male	Female
20	6000	4400
30	5000	3800
40	4100*	3200*
50	3200	2500
⩾60	2300	1800

2.4.3. *Electromyography*

The root mean square (RMS) amplitude of all raw EMGs was calculated over consecutive periods of 50 ms throughout the duration of each lift. To aid comparison of muscle activity between individuals, each subject's RMS EMGs were subsequently normalised by expressing them as a percentage of the peak RMS EMG that occurred throughout their lifts.

2.5. Statistical analysis

For the purposes of assessing the relationship between the spinal compression data and the mass lifted, the Pearson's Production Moment Correlation Coefficient was calculated using the SPSS 11.0 statistics package for Windows (SPSS Inc., Chicago, IL, USA).

3. Results

The results of this investigation showed that the magnitude mean of the L4/L5 spinal compression forces (Fig. 2) increased incrementally from the 2.5 kg lift (2041 ± 650 N) to the 22.5 kg lift (3892 ± 804 N). Additionally, the results of a Pearson's Product Moment Correlation Coefficient indicated that the relationship between the mass lifted and the lumbar compression forces was significant ($r = 0.705$, $p < 0.01$). In all cases, the peak L4/L5 compression force was found to occur approximately 0.04 seconds after the box was first displaced from the floor.

Normalised paraspinal muscle RMS EMGs (Fig. 3) also increased from the 2.5 kg (left: 70 ± 18%; right: 68 ± 11%) to the 17.5 kg (left: 91 ± 10%; right: 92 ± 13%) lifts, but showed little further increase when lifting the 22.5 kg mass (left: 94 ± 8%; right: 100 ± 0%). Peak activity in the rectus abdominis (Fig. 4) also generally increased as mass increased from 2.5 kg (left: 70 ± 30%; right: 47 ± 22%) to 22.5 kg (left: 88 ± 12%; right: 99 ± 3%).

4. Discussion

Research has shown that as the magnitude of the load increases during lifting, the moments created at the lumbar spine also increase [43], thus requiring increased stability of the spine. Specific research [23, 29] has even suggested that for the majority of workers, the maximum acceptable weight (mass) to be lifted should range from 24.3 kg to 28.9 kg and that spinal loads increase by approximately 15% for every 4.5 kg increase in mass. When lifting just 20 kg, Jorgensen et al. [23] reported a compression force of 5958.8 N and a shear force of 1499.3 N acting on the spine. Such compression and shear forces have also been shown to increase when the subject underestimates the mass to be lifted [4,5] and the height of the lift changes [31,38, 53]. For example, the loads on the lumbar spine are greater when lifting from a low height compared to a greater height, due to the increased trunk angle causing stretch to the posterior structures of the spine [25]. In addition, lifting velocity, box design and horizontal distance the object is lifted away from the centre of mass all have a correlation with increasing loads on the lumbar spine during lifting [31,49].

In 1981, the development of the NIOSH (National Institute for Occupational Safety and Health, US) lifting equation led to the production of two safe lifting limits for manual workers; the Action Limit (AL) and the Maximum Permissible Limit (MPL) [37]. In occupational lifting tasks, the AL (3433 N) was suggested to characterise a task that could be safely performed by 75% of healthy women and 99% of healthy men [11]. Alternatively, the MPL (6376 N) was suggested to describe a lifting task that was potentially unsafe for 99% of healthy women and 25% of healthy men. The test population was representative of the average person working within a number of American industries and was not specific to age or gender. The NIOSH equation recommends that a job resulting in lumbar compression values that exceed the AL of 3433 N should be considered potentially hazardous for some workers, whilst jobs associated with estimates in excess of the 6376 N MPL should be considered hazardous to most workers. However, in 1991, these guidelines were expanded to cover a wider range of occupational lifting tasks, during which time the AL and MPL were replaced by the Recommended Weight Limit (RWL) and the Lifting Index (LI) [53]. The RWL depicts the load that can be lifted by most healthy individuals for an extended period of time (e.g. 8 hrs) without increasing the risk of developing lifting-related low back pain [52]. Alternatively, the LI for a specific task is calculated by dividing the mass of the load lifted by the RWL calculated for that task [52]. Despite the fact that the AL and MPL were discarded by the committee during the revision of the NIOSH guidelines in 1991, the 3433 N compression force limit was retained from the original work, due to variability and limitations associated with the data linking compressive forces and injury [53].

In 1997, research by Jäger and Luttman [20] proposed more specific age- and gender-related limits. The suggested limits for safe lifting are summarized in Table 3.

Considering the peak spinal compression force results (Fig. 2 and Table 2) from this study, it is clear that the data indicates as the load (mass) increases, the compression force acting on the L4/L5 lumbar spine ($r = 0.705, p < 0.01$, Pearson's Product Moment) also significantly increases.

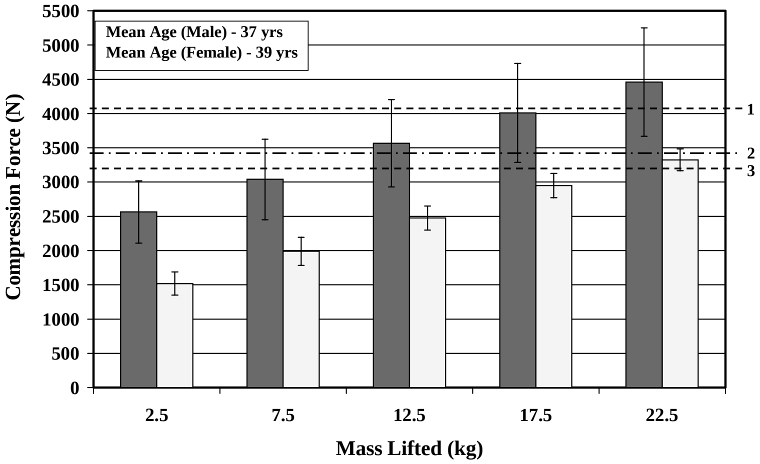

Fig. 2. Mean (± SD) peak L4/L5 compression forces for the male (dark) and female (light) subjects. The lines labelled 1 and 3 represent the 4100 N and 3200 N safe lifting limits specified by Jäger and Luttman (1997) for 40 year old males and females respectively, whilst the line labelled 2 depicts the NIOSH (1981) AL (Action Limit) safe lifting limit of 3433 N. These limits are suggested to be the maximum amount of spinal compression that can be safely tolerated by most healthy individuals.

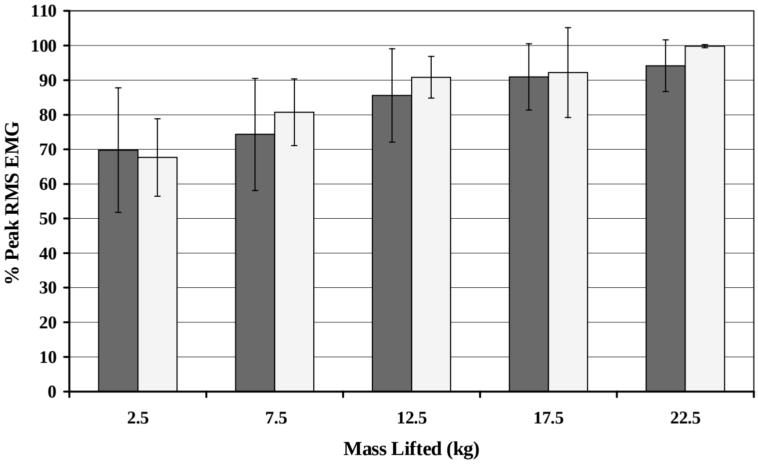

Fig. 3. Mean (± SD) normalised RMS EMG values for all subjects for the left (dark) and the right (light) erector spinae at L4.

The paraspinal muscles are required to help generate large extensor reaction moments that are produced in the low back during lifting. It is no surprise, therefore, that activity in the erector spinae also increased with the weight lifted to assist in the generation of progressively greater extensor moments (Fig. 3). A well established relationship exists between the force generated by paraspinal muscles and compressive loads acting on the lumbar spine (e.g. [33,35]). Thus, the increase in compressive loads shown in this investigation (Fig. 2) was caused largely by increases in activity and, hence, forces in the erector spinae. Increases in activity of the rectus abdominis (Fig. 4) would also likely have contributed to the elevation of compressive loads. It has previously been established that abdominal muscles play an important role in stabilising the spine during lifting and assist in the generation of compressive loads (e.g. [33,35]).

When these results are evaluated in the context of the NIOSH 1981 guidelines for the AL of 3433 N load acting on the lumbar spine, a number of important comparisons can be made. Firstly, it is evident that in four of the six subjects (67%), this limit was exceeded in the 22.5 kg lifting situation. Furthermore, three of these four subjects were male. Hence, it is possible that this limit is too low when male subjects are considered or that the task of lifting 22.5 kg creates excessive spinal loading in male subjects. In two cases, again both male

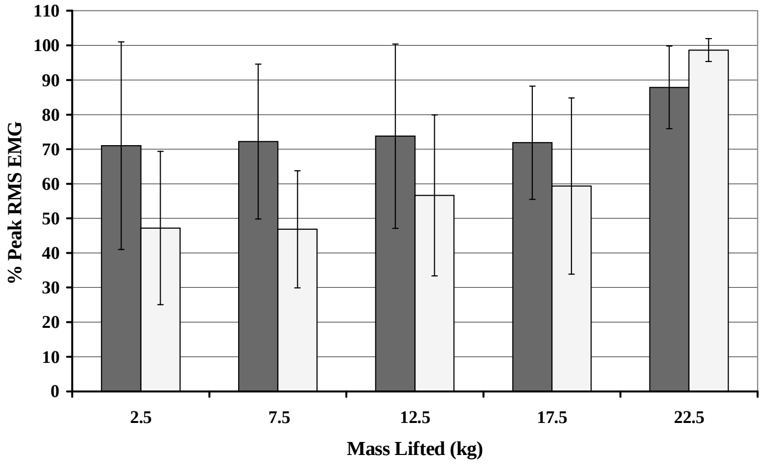

Fig. 4. Mean (± SD) normalised RMS EMG values for all subjects for the left (dark) and the right (light) rectus abdominis.

subjects, this limit was exceeded in the 12.5 kg, 17.5 kg and 22.5 kg lifting assessments. In particular subject 3, who was the heaviest and tallest male, exceeded this limit when lifting only a 7.5 kg mass.

Comparison of these results to the age- and gender-specific limits presented by Jäger and Luttman [20], again, identified that four of the six subjects exceeded the safe lifting limits in the 22.5 kg test, but this time this included two male and two female subjects. However, in contrast, only subject 3 (the same subject again) exceeded the guidelines in any other lifting condition (12.5, 17.5 and 22.5 kg tests). Unlike the other participants, subject 3 tended to hold the box away from his body when lifting it, which would have consequently increased the length of the lever arm and contributed to the higher compression forces experienced by this subject. Although young healthy males have been suggested to be capable of enduring compression forces of up to 12–15 kN [1], separate research has indicated that compression strength is negatively correlated with age [22]. Based on the results of cadaveric studies, Jäger and Luttmann [21] suggested that the mean lumbar compression strength of a 40 year old male ranged between 5.5 and 7.5 kN, as compared to 4.5 and 5.5 kN for 40 year old females.

Although none of the six subjects exceeded the NIOSH 1981 Maximum Permissible Limit (MPL) of 6376 N in any of the tests conducted, it is important to point out that the compression data presented for these subjects were derived from static calculations. Unlike a dynamic approach, static calculations neglect the inertial effects and the acceleration of the external mass and the segments, in addition to the possible effects of co-contraction and intra-abdominal pressure [24]. According to the findings of previous research, techniques that fail to consider these parameters in the assessment of a dynamic task, generally underestimate the magnitude of dynamic spinal loading by between 18 and 67% [8,12,34,36]. As a consequence, it is suggested that the compression force data presented in this manuscript be considered with caution.

The results from this study and the comparisons made with the NIOSH 1981 and Jäger and Luttman 1997 recommendations can be summarised as follows. Firstly, there seems to be an issue (whichever guidelines are used) of lifting a mass of 22.5 kg or more. In certain Australian industries it is often the case that a subject is asked to lift more than 22.5 kg before they are allowed to return to work. Considering the results of this study and the potential for an underestimation of the actual compression forces due to the use of a static model, it is possible that such tests may place the subject at an unnecessarily high risk of injury. This may have particularly important implications if subjects are being assessed for return to work following an injury.

Secondly, it appears that in relation to the two guidelines, both are presenting safe lifting limits that are generally comparable, although the gender-specific values of the Jäger and Luttman 1997 work are lower for females and higher for male subjects than those presented by NIOSH. Hence, using these guidelines may present an additional associated risk for the male subjects since in many cases in this experiment it was the male subjects who exceeded the safe lifting limits.

Thirdly, it is also evident from these results that subject 3 (male) had a particular problem with lifting technique and spinal loading. Subject 3 was potentially at risk when lifting only a 7.5 kg mass. This subject used lifting as part of his normal working day and it was, hence, important to provide this subject with some guidelines for safer lifting. It is envisaged that within the workplace, there will be many more subjects who are not familiar with how to lift correctly. In this context however, it is important, again, to point out that subject 3 was, in fact, the heaviest and the tallest subject in the experiment and this may have important implications for loading on the spine and safe lifting technique. This finding may suggest that, in the future, safe lifting guidelines should take into consideration an individual's body mass, particularly given that previous research has indicated that the compression strength of the lumbar vertebrae is positively associated with body mass [3,16].

In a recent paper conducted to assess current practices for workplace assessments and functional capacity evaluations for therapists in Australia, Innes and Straker [19] identified the need for standardisation, validity and generalisability in the many qualitative and quantitative work capacity evaluations that are used. Furthermore, if some return to work evaluations require subjects to lift loads successfully it is critical that such loading is standardised and quantified. In particular, there is a strong need for further research into the quantitative nature of loading on the spine that such lifting tests and specific lifting exercises may impose [44].

This study has shown that lifting masses of 22.5 kg or more to the typical height of a work bench can produce loads on the spine that are considered potentially hazardous. Furthermore, the results indicate that there is a clear concern if such lifting tasks are used for return to work evaluations following injury. Further research performed with more subjects is needed to confirm these results in the context of this and other work capacity evaluations used within Australia and, indeed, around the world. Finally, it is also obvious (primarily from the results of subject 3) that an "easy to read" lifting guideline leaflet would be valuable in educating people who regularly perform lifting tasks and yet have limited knowledge on how to do this safely. A study on this topic alone would provide valuable information for both health care and Australian government organisations.

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