6-1-2018

Effects of the weight configuration of hand load on trunk musculature during static weight holding

Saman Madinei
West Virginia University

Xiaopeng Ning
West Virginia University

HHS Public Access
Author manuscript
Ergonomics. Author manuscript; available in PMC 2019 June 01.

Published in final edited form as:
Ergonomics. 2018 June ; 61(6): 831–838. doi:10.1080/00140139.2017.1387675.

Effects of the weight configuration of hand load on trunk musculature during static weight holding

Saman Madinei and **Xiaopeng Ning**
The Ergonomics Laboratory, Department of Industrial and Management Systems Engineering, West Virginia University, Morgantown, WV, USA

Abstract

The performance of manual material handling tasks is one major cause of lower back injuries. In the current study, we investigated the influence of the weight configuration of hand loads on trunk muscle activities and the associated spinal stability. Thirteen volunteers each performed static weight-holding tasks using two different 9 kg weight bars (with medial and lateral weight configurations) at two levels of height (low and high) and one fixed horizontal distance (which resulted in constant spinal joint moment across conditions). Results of the current study demonstrated that holding the laterally distributed load significantly reduced activation levels of lumbar and abdominal muscles by 9–13% as compared with holding the medially distributed load. We believe such an effect is due to an elevated rotational moment of inertia when the weight of the load is laterally distributed. These findings suggest that during the design and assessment of manual material handling tasks, such as lifting and carrying, the weight configuration of the hand load should be considered.

Keywords

Trunk biomechanics; spinal stability; weight configuration; manual material handling; electromyography

1. Introduction

Epidemiological studies have demonstrated that low back pain (LBP) is associated with extraneous work, awkward working postures, and repetitive bending and/or lifting tasks (Bernard 1997; Hoogendoorn et al. 2000; Mariconda et al. 2007; Suri et al. 2010). Existing evidence shows that excessive mechanical loading on the spine could lead to LBP (Neumann et al. 1999; Marras 2000; Kerr et al. 2001; Bakker et al. 2007). In addition, spinal injury is also linked to spinal stability, which is achieved by the synergistic and coherent interplay of spinal subsystems, including muscles, ligaments, bones and the nervous system (Bergmark 1989; Panjabi 1992; Cholewicki and McGill 1996). Functional impairment of spinal tissues and unstable spinal motions (ie uncontrolled intervertebral movements) could lead to improper distribution of mechanical loading to the spinal structure, causing buckling and failure of spinal structures, and therefore, elevating the risk of spinal injuries and pain

CONTACT Xiaopeng Ning, xiaopeng.ning@mail.wvu.edu.

(Cholewicki and McGill 1996; Granata and Marras 2000; Panjabi 2003; Granata and Gottipati 2008).

Spinal injuries are often associated with the performance of manual material handling tasks (Marras et al. 1993; Norman et al. 1998; Waters et al. 2006). Previous studies have found that the stability of spine and trunk muscular activity can be influenced by trunk posture (Granata and Wilson 2001; Arjmand and Shirazi-Adl 2005), lifting techniques (Bazrgari, Shirazi-Adl, and Arjmand 2007; Rose, Mendel, and Marras 2013), work experience (Plamondon et al. 2010), prior knowledge of load magnitude (Elsayed et al. 2015) and prolonged working hours as well as the associated muscle fatigue (Granata, Slota, and Wilson 2004; Granata and Gottipati 2008). It was also found that the magnitude of external loading and the asymmetry of the load handling posture (eg sagittally symmetric vs. asymmetric to the torso) could influence spinal stability and trunk muscle co-contraction (Lavender et al. 1992; Shirazi-Adl et al. 2005). In addition, handling loads at different vertical heights could also influence spinal stability; previous studies have found reduced spinal stability when handling loads at a higher position (eg over the shoulder level) as compared to a lower position (eg at waist level) (Granata and Orishimo 2001; Ning et al. 2014). It was also noted that the configuration of an external load could potentially influence spinal stability during weight handling. Changes of the weight distribution of a hand load result in changes in its moment of inertia; when performing manual material handling such a change could cause the trunk to lose its balance and lumbar vertebrae to buckle especially under perturbation (Preuss and Fung 2005).

Figure 1 shows two different configurations of the same weight magnitude on a weight bar. The rotational moment of inertia for each configuration can be calculated using Eq. (1), where I is the total moment of inertia for a specific weight around the axis of rotation. I_{CM_i} is the moment of inertia of component 'i' (eg a weight disc) around its centre of mass; M_i represents the mass of the component 'i'; and R_i is the distance from the centre of mass of the component 'i' to the axis of the rotation. When discs are located farther away from the midpoint of the bar, the system has a larger rotational moment of inertia. As shown in Equation (2) (where T is the total torque; I is the total moment of inertia and α is the angular acceleration), under the same amount of torque (generated by external perturbation, unbalanced hand force, etc.), a more laterally distributed load will experience smaller amount of angular acceleration and deviation due to its larger moment of inertia as compared to a more medially distributed load. In mechanical systems, this concept is used to create smoother motions (eg fly-wheels used in engines). Considering human biomechanics, this concept is also used to improve postural stability. For example, when performing weight lifting, weight discs are located on both sides of a barbell instead of at its centre; also, during tightrope walking, acrobats hold a long pole to enhance their whole-body stability and balance (McLester and Pierre 2007).

$$I = \sum_{i=1}^{n} (I_{CM_i} + M_i R_i^2) \quad (1)$$

$$T = I \times \alpha \quad (2)$$

For a rigid mechanical structure, supporting two symmetrical objects that have the same amount of weight but different configurations (as shown in Figure 1) should require the same and constant supporting forces at the points of contact. However, when these two weights are handled by humans, results can be quite different. The biomechanical system of the human body relies constantly on neuromuscular feedback to continuously adjust postures and force outputs even when performing static motions (Keele 1968). Previous research shows that signals representing an imbalance are generated and understood by the brain with a delay, and corrective muscle reactions to this information are consequently slowed down, which may result in slight perturbations of body parts (McLester and Pierre 2007; Thelen, Schultz, and Ashton-Miller 1994). When small disturbances from the neuromuscular system occur (eg a natural hand sway and a slightly imbalanced hand force during static weight holding), the weight with greater moment of inertia would experience smaller angular acceleration and less movement (McLester and Pierre 2007).

The purpose of the current study was to understand the influence of the weight configuration of hand load on trunk muscle activities during static weight holding. Previous studies have found that during the performance of manual material handling tasks, to increase the stability of the spine, higher levels of trunk muscle co-contraction (ie an increase in both agonistic and antagonistic muscle activities) were often observed (Chaffin et al. 1999; Lee, Rogers, and Granata 2006). Such a mechanism could enhance the overall stiffness of the trunk and, subsequently, improve spinal stability (Cholewicki, Simons, and Radebold 2000; Granata and Marras 2000; Brown and Potvin 2005; Reeves, Narendra, and Cholewicki 2007; Stokes, Gardner-Morse, and Henry 2011). Therefore, it was hypothesised that when handling the same magnitude of external loading, a more medially distributed load configuration would result in higher levels of trunk muscle co-contraction as compared to a more laterally distributed load configuration.

2. Method

2.1. Participants

Thirteen healthy male volunteers (Average ± SD) (age 29.3 ± 3.0 years, body mass 70.6 ± 7.5 kg, body height 174.3 ± 5.6 cm) from the student population of West Virginia University participated in this study. Participants with a history of shoulder pain, LBP or upper extremity injuries were excluded from this study. Prior to data collection, informed consent forms were obtained from all participants. The experimental design and procedures were approved by the Institutional Review Board of West Virginia University.

2.2. Experimental design

The load weight configuration and the load handling height were considered as two independent variables (referred to as CONFIGURATION and HEIGHT, respectively, hereinafter). CONFIGURATION has two levels: medially distributed (9 kg weight located at the midpoint of the bar) and laterally distributed (two 4.5 kg weights located at the two ends of the bar with a distance of 100 cm). The HEIGHT also has two levels: high and low, which is defined as 25 cm above or below the shoulder height, respectively, for each participant. To maintain a constant external loading to the spine, the horizontal distance between the projected location of the load's centre of mass and the midpoint of the participant's ankles remained at 45 cm throughout all trials (Zhou, Dai, and Ning 2013). Hand locations were also controlled: the middle finger of each hand was 10 cm away from the mid-point of the bar for all trials. The combination of the two independent variables created 4 different conditions; each condition was repeated 3 times, resulting in a total of 12 trials. Dependent variables included the NEMG activities of Erector Spinae (ES), Multifidus (MU), Rectus Abdominus (RA) and External Oblique (EO) muscles.

2.3. Apparatus and equipment

A custom-made wooden stand was utilised as a guide to help participants control the height and the horizontal distance of the load during each trial. Weight discs were secured to two identical wooden bars to create the two weight configuration conditions. Eight bipolar surface EMG electrodes (Bagnoli, Delsys, Inc., Boston, MA, USA) were placed over the skin of the left and right ES (4 cm lateral to the L3 spinous process), left and right MU (2 cm lateral to the L5 spinous process) (Ning et al. 2011; Hu, Ning, and Nimbarte 2013), left and right RA (2 cm above and 3 cm lateral to the umbilicus), and left and right EO (approximately 15 cm lateral to the umbilicus) (Cholewicki and VanVliet IV 2002). The sampling frequency of EMG was set at 1024 Hz. The placements of EMG electrodes are shown in Figure 2(a) and (b). A lumbar dynamometer with a back flexion–extension module (Humac Norm, CSMi, MA, USA) was used in this study to secure participant's lower extremities and provide static resistance while performing maximum voluntary contractions (MVC) (described in more detail in the *Procedure* section).

2.4. Procedure

Upon arrival, participants were given a thorough description of the experiment and then signed their informed consent forms. Prior to the data collection, participants performed a five-minute warm-up session to stretch their shoulder and back muscles and become familiar with the protocol of the experiment. When finished, surface EMG electrodes were then attached to the above-described locations with double-sided tape. During MVC trials, participants were secured in a 20° trunk forward flexion posture (Marras and Mirka 1993) and performed isometric trunk maximum voluntary flexion and extension contractions each with two repetitions. The 20° trunk forward flexion posture was selected because, in this posture, low back and abdominal muscles are close to their resting lengths, which will allow them to generate maximal contractile tensions (Chaffin, Andersson, and Martin 2006). Each MVC trial lasted ~6 s and, at least, two minutes of rest was given between trials to avoid muscle fatigue (Caldwell et al. 1974; Marras and Davis 2001). Participants then performed a total of 12 weight-holding trials. Each trial required participants to hold a weight bar in front of their torsos with a fixed horizontal distance, a predetermined vertical height (ie 25 cm above or below acromion points) and a fixed hand posture for 10 s (Figure 2(c) and (d)). In each trial, weight was brought to and taken away from participants by an experimenter, therefore, no weight lifting or lowering was needed for participants. At least one minute of rest was provided between trials to avoid shoulder and back muscle fatigue.

2.5. Data processing and analysis

EMG data were first filtered using a 10–500 Hz band-pass filter and a notch filter at 60 Hz and its aliases. The filtered EMG signals were then rectified and smoothed using a 100-data point sliding window. Mean EMG values from experimental trials were then normalised with respect to each muscle's maximal EMG, collected from MVC trials. Due to the sagittally symmetric nature of the weight-holding task, normalised EMG (NEMG) from left and right sides of ES, MU, RA and EO were averaged to generate NEMG for the correspondent muscles.

2.6. Statistical analysis

All statistical analyses were performed using Minitab 17 (Minitab Inc., PA, USA). The validity of ANOVA assumptions (normality of residuals, equality of variances, etc.) was tested on all dependent variables, and the ones which did not satisfy those assumptions were transformed until all assumptions were satisfied (Montgomery 2012). Multivariate ANOVA (MANOVA) analysis was subsequently performed to assess the effects of independent variables and their interactions on all dependent variables, collectively. Significant effects were further tested using univariate ANOVA. A criterion p-value of 0.05 was selected.

3. Results

In agreement with our initial hypothesis, the results of MANOVA revealed significant main effects of both independent variables (ie CONFIGURATION and HEIGHT) on all dependent variables (NEMG values of ES, MU, RA and EO muscles). The interaction effect was not significant and, therefore, was not further analysed (Table 1). Results of univariate ANOVA illustrated that both independent variables substantially influenced all back and abdominal muscles. As shown in Figures 3 and 4, higher NEMG values were observed in the higher load handling position and with the medial load condition for all trunk muscles. Whereas the lower load handling position and the laterally distributed load generated lower NEMG values. More specifically, when holding a medially distributed load, NEMG of ES and MU muscles increased by 2.0% (24.0–26.0%) and 3.0% (29.7–32.7%), respectively; abdominal muscle activity also elevated by 0.5% (5.4–5.9%) and 1.0% (8.6–9.6%), respectively, for RA and EO. Holding the load at a higher position resulted in a 3.8% (23.0–26.8%), 3.5% (29.4–32.9%), 1.5% (5.0–6.5%) and 1.5% (8.3–9.8%) increase in NEMG for ES, MU, RA and EO muscles, respectively, as compared to holding the load at a lower position.

4. Discussion

The main purpose of the current study was to understand whether different weight configurations of the hand load could influence trunk muscle activities and the associated spinal stability during weight holding. As described earlier, when holding the same magnitude of load, different weight configuration could generate a different rotational moment of inertia. Such difference could result in changes in neuromuscular control and muscle activation patterns to cope with external perturbations or unbalanced hand forces.

We hypothesised that when handling the same magnitude of external loading, a more medially distributed load configuration would result in higher levels of trunk muscle co-contraction as compared to a more laterally distributed load configuration. Results of the current study demonstrated increased EMG activities among lumbar extensor muscles as well as abdominal muscles; these results supported our initial hypotheses.

In the current study, when holding a more medially distributed weight, the moment of inertia decreases (as suggested by Equation 1) and the human trunk becomes potentially less stable; any small disturbances to the load (eg resulting from the naturally imbalanced hand forces due to delays in neuromuscular feedback) could generate greater angular acceleration and displacement to the load. In turn, larger trunk muscle forces would be needed to stabilise the system and bring the load back to its equilibrium. An elevated level of trunk muscle co-contraction during daily activities can be mechanically and energetically costly (Marras and Mirka 1990). While the antagonistic co-contraction contributes to both increased compression and stability, stability has been found to increase proportionately more than compression (Granata and Marras 2000).

Figure 5 demonstrates two typical EMG profiles of an ES muscle during the course of two weight-holding trials. As can be observed, when holding a laterally distributed load, we often recorded much more stable EMG activities as compared to holding a medially distributed load. Additionally, in agreement with previous studies (Granata and Orishimo 2001; Ning et al. 2014), higher levels of trunk muscle activities were observed when holding a load in the higher position. Such an increase in trunk muscle co-contraction is possibly used to increase the stiffness of the trunk and compensate for the reduced trunk and spinal stability (Granata and Marras 2000; Granata and Orishimo 2001). Another interesting finding of this study was that in the abdominal region, EO muscles demonstrated higher NEMG compared to RA muscles. We believe this is mainly due to the differences in the muscle fibre orientation and the location of these two muscles. RA is located in the centre of the abdomen, and its muscle fibres are vertically oriented whereas EO is located laterally to the RA, and its muscle fibres are oriented with a slightly oblique angle (Criswell 2010). This location and muscle fibre orientation enabled the EO muscle to play an important role in balancing rotational moment, such as what is needed in the current experiment.

Although both main effects significantly influenced trunk muscle activities during weight holding, the actual differences between the levels were relatively small. For example, compared to the medially distributed load configuration, holding a laterally distributed load reduced the NEMG of ES, MU, EO and RA muscles by 9, 10, 13 and 9%, respectively. However, the actual changes in magnitude were only 2.0, 3.0, 1.0 and 0.5% of the maximal EMG values, respectively. We believe these observed small differences between levels were mainly due to the fact that our testing conditions were restricted to relatively simple, conservative and controlled conditions. For instance, to avoid back and shoulder muscle fatigue, the horizontal distance of the load was controlled at 45 cm across all trials and the duration of each weight-holding task was limited to only 10 s. In addition, to further reduce variance, we used static weight-holding tasks instead of dynamic motions. It is highly possible that in real-working scenarios where workers are required to perform dynamic tasks with more demanding task requirements and the possibility of experiencing muscle fatigue and external perturbations, the influence of weight configuration on trunk muscle activation levels and spinal stability can be magnified dramatically.

Manual material handling tasks, such as weight lifting and carrying are prevalent in a number of industries such as construction, service and transportation. Repetitively handling heavy loads and/or for a prolonged period of time (eg construction workers carrying cement bags, baggage handlers moving bags and suitcases from conveyer belt, couriers delivering goods in boxes) can lead to spinal instability and result in spinal injury (Beaudette, Graham, and Brown 2014). Results of this study suggest that to carry the same amount of weight, a symmetrical and more laterally distributed load requires less back and abdominal muscle co-activation, which may be associated with a relatively more stable spine and a lower level of spine compression as compared to a more medially distributed load.

Findings from the current study can be applied in numerous work scenarios. For instance, when construction workers carry cement bags, to enhance trunk stability and reduce spinal loading, these bags should be placed horizontally (instead of vertically) and in a close-to-abdomen position. Similarly, in air transportation, when a baggage handler carries a bag with both hands, holding handles along the long axis of the bag and keeping it close to the abdomen would help reduce the risk of spinal injury.

Finally, a number of limitations of this study need to be noted: first, task duration was controlled at 10 s to avoid shoulders and trunk muscle fatigue; longer task duration and the associated muscle fatigue could further influence the results, which warrant future investigation. Second, only one level of weight and one specific hand and trunk posture were tested in the current study; heavier weight and more complex hand and body postures (eg asymmetric weight holding) were not explored. Third, only young, male participants were recruited. Older individuals and female participants may generate different results.

5. Conclusions

Results of the current study demonstrate that changes in the weight configuration of the hand load significantly influenced trunk muscle activities and, potentially, the associated spinal stability during weight holding. This finding suggests that the weight configuration of the hand load should be considered during the design and assessment of manual material handling tasks, such as weight lifting and carrying.

References

Arjmand N, Shirazi-Adl A. Biomechanics of Changes in Lumbar Posture in Static Lifting. Spine. 2005; 30(23):2637–2648. [PubMed: 16319750]

Bakker EW, Verhagen AP, Lucas C, Koning HJ, de Haan RJ, Koes BW. Daily Spinal Mechanical Loading as a Risk Factor for Acute Non-Specific Low Back Pain: A Case–Control Study Using the 24-Hour Schedule. European Spine Journal. 2007; 16(1):107–113. [PubMed: 16649030]

Bazrgari B, Shirazi-Adl A, Arjmand N. Analysis of Squat and Stoop Dynamic Liftings: Muscle Forces and Internal Spinal Loads. European Spine Journal. 2007; 16(5):687–699. [PubMed: 17103232]

Beaudette SM, Graham RB, Brown SH. The Effect of Unstable Loading versus Unstable Support Conditions on Spine Rotational Stiffness and Spine Stability during Repetitive Lifting. Journal of Biomechanics. 2014; 47(2):491–496. [PubMed: 24287401]

Bergmark A. Stability of the Lumbar Spine: A Study in Mechanical Engineering. Acta Orthopaedica Scandinavica. 1989; 60(sup230):1–54. [PubMed: 2929276]

Bernard, BP., editor. Musculoskeletal Disorders and Workplace Factors: A Critical Review of Epidemiologic Evidence for Work-Related Musculoskeletal Disorders of the Neck, Upper Extremity, and Lower Back. Cincinnati, OH: Department of Health and Human Services; 1997.

Brown SH, Potvin JR. Constraining Spine Stability Levels in an Optimization Model Leads to the Prediction of Trunk Muscle Cocontraction and Improved Spine Compression Force Estimates. Journal of Biomechanics. 2005; 38(4):745–754. [PubMed: 15713295]

Caldwell LS, Chaffin DB, Dukes-Dobos FN, Kroemer KHE, Laubach LL, Snook SH, Wasserman DE. A Proposed Standard Procedure for Static Muscle Strength Testing. The American Industrial Hygiene Association Journal. 1974; 35(4):201–206. [PubMed: 4822353]

Chaffin DB, Stump BS, Nussbaum MA, Baker G. Low-back Stresses When Learning to use a Materials Handling Device. Ergonomics. 1999; 42(1):94–110. [PubMed: 9973874]

Chaffin, DB., Andersson, G., Martin, BJ. Occupational Biomechanics. Hoboken, NJ: Wiley-Interscience; 2006.

Cholewicki J, McGill SM. Mechanical Stability of the *in Vivo* Lumbar Spine: Implications for Injury and Chronic Low Back Pain. Clinical Biomechanics. 1996; 11(1):1–15. [PubMed: 11415593]

Cholewicki J, Simons AP, Radebold A. Effects of External Trunk Loads on Lumbar Spine Stability. Journal of Biomechanics. 2000; 33(11):1377–1385. [PubMed: 10940396]

Cholewicki J, VanVliet JJ IV. Relative Contribution of Trunk Muscles to the Stability of the Lumbar Spine during Isometric Exertions. Clinical Biomechanics. 2002; 17(2):99–105. [PubMed: 11832259]

Criswell, E. Cram's Introduction to Surface Electromyography. London: Jones & Bartlett; 2010.

Elsayed W, Farrag A, El-Sayyad M, Marras WS. Changes in Muscular Activity and Lumbosacral Kinematics in Response to Handling Objects of Unknown Mass Magnitude. Human Movement Science. 2015; 40:315–325. [PubMed: 25662505]

Granata KP, Marras WS. Cost–benefit of Muscle Cocontraction in Protecting against Spinal Instability. Spine. 2000; 25(11):1398–1404. [PubMed: 10828922]

Granata KP, Orishimo KF. Response of Trunk Muscle Coactivation to Changes in Spinal Stability. Journal of Biomechanics. 2001; 34(9):1117–1123. [PubMed: 11506782]

Granata KP, Slota GP, Wilson SE. Influence of Fatigue in Neuromuscular Control of Spinal Stability. Human Factors. 2004; 46(1):81–91. [PubMed: 15151156]

Granata KP, Gottipati P. Fatigue Influences the Dynamic Stability of the Torso. Ergonomics. 2008; 51(8):1258–1271. [PubMed: 18608477]

Granata KP, Wilson SE. Trunk Posture and Spinal Stability. Clinical Biomechanics. 2001; 16(8):650–659. [PubMed: 11535346]

Hoogendoorn WE, Bongers PM, de Vet HC, Douwes M, Koes BW, Miedema MC, Ariëns GA, Bouter LM. Flexion and Rotation of the Trunk and Lifting at Work Are Risk Factors for Low Back Pain: Results of a Prospective Cohort Study. Spine. 2000; 25(23):3087–3092. [PubMed: 11145822]

Hu B, Ning X, Nimbarte AD. The Changes of Lumbar Muscle Flexion–relaxation Response due to Laterally Slanted Ground Surfaces. Ergonomics. 2013; 56(8):1295–1303. [PubMed: 23730975]

Keele SW. Movement Control in Skilled Motor Performance. Psychological Bulletin. 1968; 70(6p1):387.

Kerr MS, Frank JW, Shannon HS, Norman RW, Wells RP, Neumann WP, Bombardier C. Ontario Universities Back Pain Study Group. Biomechanical and Psychosocial Risk Factors for Low Back Pain at Work. American Journal of Public Health. 2001; 91(7):1069–1075. [PubMed: 11441733]

Lavender SA, Tsuang YH, Andersson GBJ, Hafezi A, Shin CC. Trunk Muscle Cocontraction: The Effects of Moment Direction and Moment Magnitude. Journal of Orthopaedic Research. 1992; 10(5):691–700. [PubMed: 1500981]

Lee PJ, Rogers EL, Granata KP. Active Trunk Stiffness Increases with Co-contraction. Journal of Electromyography and Kinesiology. 2006; 16(1):51–57. [PubMed: 16099678]

Mariconda M, Galasso O, Imbimbo L, Lotti G, Milano C. Relationship between Alterations of the Lumbar Spine, Visualized with Magnetic Resonance Imaging, and Occupational Variables. European Spine Journal. 2007; 16(2):255–266.

Marras WS, Mirka GA. Muscle Activities during Asymmetric Trunk Angular Accelerations. Journal of Orthopaedic Research. 1990; 8(6):824–832. [PubMed: 2213339]

Marras WS, Mirka GA. Electromyographic Studies of the Lumbar Trunk Musculature during the Generation of Low-level Trunk Acceleration. Journal of Orthopaedic Research. 1993; 11(6):811–817. [PubMed: 8283325]

Marras WS. Occupational Low Back Disorder Causation and Control. Ergonomics. 2000; 43(7):880–902. [PubMed: 10929824]

Marras WS, Davis KG. A Non-MVC EMG Normalization Technique for the Trunk Musculature: Part 1. Method Development. Journal of Electromyography and Kinesiology. 2001; 11(1):1–9. [PubMed: 11166603]

Marras WS, Lavender SA, Leurgans SE, Rajulu SL, Allread GW, Fathallah FA, Ferguson SA. The Role of Dynamic Three-Dimensional Trunk Motion in Occupationally-related Low Back Disorders. Spine. 1993; 18(5):617–628. [PubMed: 8484154]

McLester, J., Pierre, PS. Applied Biomechanics: Concepts and Connections. 1. Florence, KY: Cengage Learning; 2007.

Montgomery, DC. Design and Analysis of Experiments. New York: Wiley; 2012.

Neumann WP, Wells RP, Norman RW, Andrews DM, Frank J, Shannon HS, Kerr MS. Comparison of Four Peak Spinal Loading Exposure Measurement Methods and Their Association with Low-back Pain. Scandinavian Journal of Work, Environment & Health. 1999:404–409.

Ning X, Haddad O, Jin S, Mirka GA. Influence of Asymmetry on the Flexion Relaxation Response of the Low Back Musculature. Clinical Biomechanics. 2011; 26(1):35–39. [PubMed: 20943296]

Ning X, Zhou J, Dai B, Jaridi M. The Assessment of Material Handling Strategies in Dealing with Sudden Loading: The Effects of Load Handling Position on Trunk Biomechanics. Applied Ergonomics. 2014; 45(6):1399–1405. [PubMed: 24766903]

Norman R, Wells R, Neumann P, Frank J, Shannon H, Kerr M. The Ontario Universities Back Pain Study. A Comparison of Peak Vs Cumulative Physical Work Exposure Risk Factors for the Reporting of Low Back Pain in the Automotive Industry. Clinical Biomechanics. 1998; 13(8):561–573. [PubMed: 11415835]

Panjabi MM. The Stabilizing System of the Spine. Part I. Function, Dysfunction, Adaptation, and Enhancement. Clinical Spine Surgery. 1992; 5(4):383–389.

Panjabi MM. Clinical Spinal Instability and Low Back Pain. Journal of Electromyography and Kinesiology. 2003; 13(4):371–379. [PubMed: 12832167]

Plamondon A, Denis D, Delisle A, Larivière C, Salazar E. IRSST MMH research group. Biomechanical Differences between Expert and Novice Workers in a Manual Material Handling Task. Ergonomics. 2010; 53(10):1239–1253. [PubMed: 20865607]

Preuss R, Fung J. Can Acute Low Back Pain Result from Segmental Spinal Buckling during Sub-maximal Activities? A Review of the Current Literature. Manual Therapy. 2005; 10(1):14–20. [PubMed: 15681264]

Reeves NP, Narendra KS, Cholewicki J. Spine Stability: The Six Blind Men and the Elephant. Clinical Biomechanics. 2007; 22(3):266–274. [PubMed: 17210212]

Rose JD, Mendel E, Marras WS. Carrying and Spine Loading. Ergonomics. 2013; 56(11):1722–1732. [PubMed: 24073718]

Shirazi-Adl A, El-Rich M, Pop DG, Parnianpour M. Spinal Muscle Forces, Internal Loads and Stability in Standing under Various Postures and Loads—Application of Kinematics-based Algorithm. European Spine Journal. 2005; 14(4):381–392. [PubMed: 15452703]

Stokes IA, Gardner-Morse MG, Henry SM. Abdominal Muscle Activation Increases Lumbar Spinal Stability: Analysis of Contributions of Different Muscle Groups. Clinical Biomechanics. 2011; 26(8):797–803. [PubMed: 21571410]

Suri P, Hunter DJ, Jouve C, Hartigan C, Limke J, Pena E, Swaim B, Li L, Rainville J. Inciting Events Associated with Lumbar Disc Herniation. The Spine Journal. 2010; 10(5):388–395. [PubMed: 20347617]

Thelen DG, Schultz AB, Ashton-Miller JA. Quantitative Interpretation of Lumbar Muscle Myoelectric Signals during Rapid Cyclic Attempted Trunk Flexions and Extensions. Journal of Biomechanics. 1994; 27(2):157–167. [PubMed: 8132683]

Waters T, Yeung S, Genaidy A, Callaghan J, Barriera-Viruet H, Deddens J. Cumulative Spinal Loading Exposure Methods for Manual Material Handling Tasks. Part 1: Is Cumulative Spinal Loading Associated with Lower Back Disorders? Theoretical Issues in Ergonomics Science. 2006; 7(2): 113–130.

Zhou J, Dai B, Ning X. The Assessment of Material Handling Strategies in Dealing with Sudden Loading: Influences of Foot Placement on Trunk Biomechanics. Ergonomics. 2013; 56(10):1569–1576. [PubMed: 23906047]

Practitioner summary

Elevated trunk muscle activities were found when holding a medially distributed load vs. a laterally distributed load (with an equivalent external moment to the spine), indicating a reduced spinal stability due to the reduced rotational moment of inertia. The configuration of the hand load should be considered when evaluating manual material handling tasks.

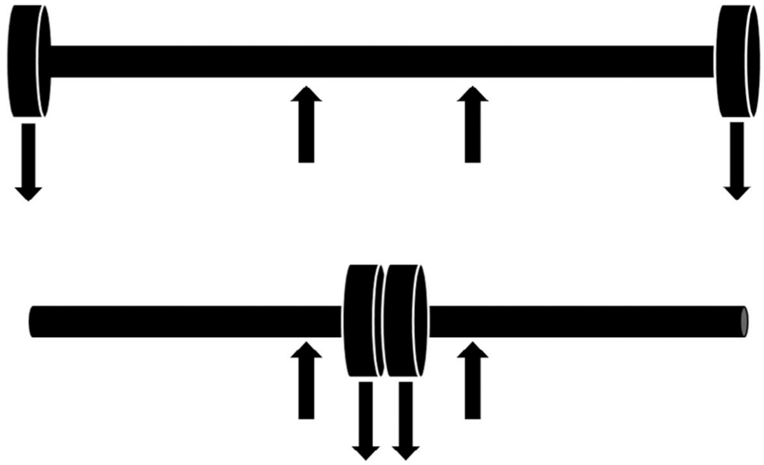

Figure 1.

A demonstration of two objects with the same amount of weight but different configurations (the top panel shows a laterally distributed weight configuration and the bottom panel shows a medially distributed weight configuration), upward arrows indicate the counterbalancing supporting force and downward arrows indicate gravitational forces.

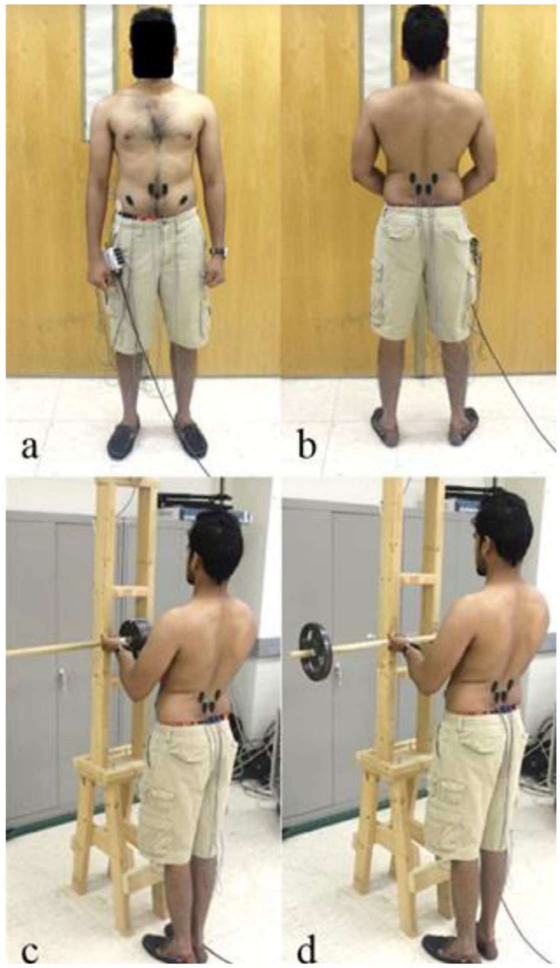

Figure 2.

A demonstration of the location of EMG sensors (a, b), data collection apparatus and the postures participants used when holding a medially distributed weight (c) and a laterally distributed weight (d).

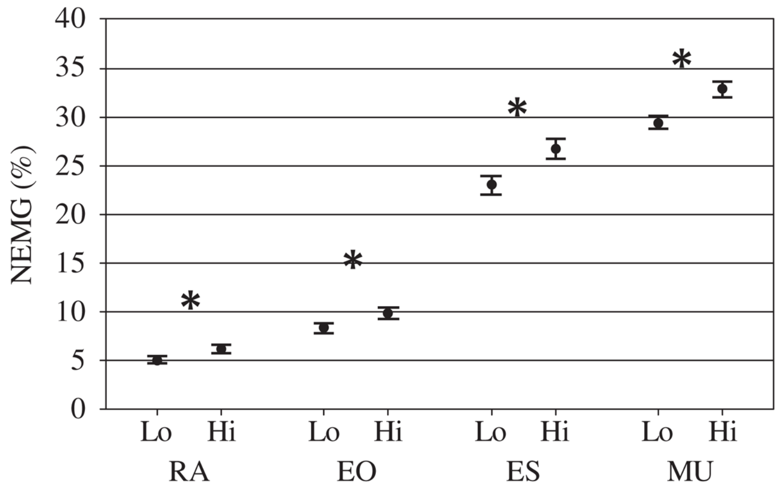

Figure 3.

Averaged activation levels of trunk muscles when holding load in high (Hi) vs. low (Lo) conditions. Bars indicate the corresponding standard error and asterisks denote statistical significance between two levels.

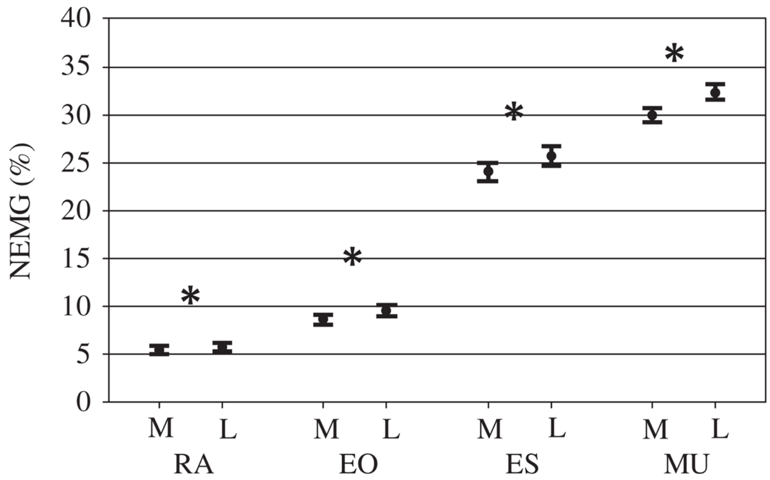

Figure 4.

Averaged activation levels of trunk muscles when holding a laterally distributed weight (L) vs. a medially distributed weight (M). Bars indicate the corresponding standard error and asterisks denote statistical significance between two levels.

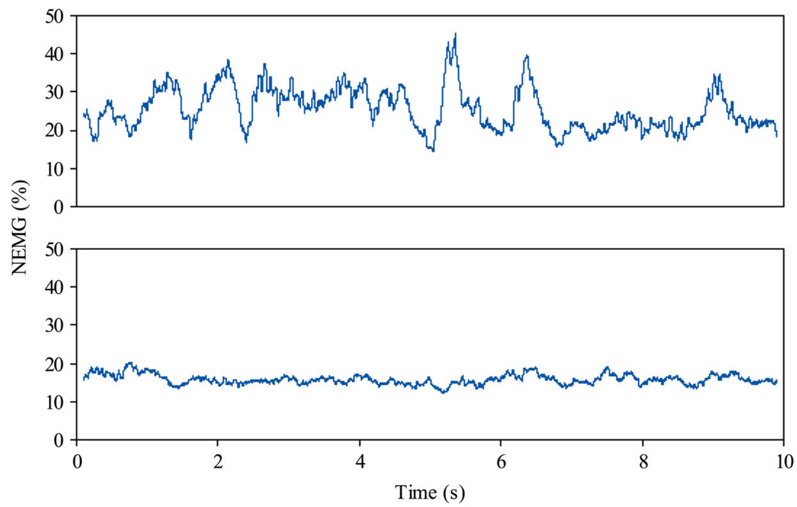

Figure 5.
A demonstration of typical EMG profiles of an ES muscle when holding a medially distributed weight (A) vs. a laterally distributed weight (B).

Table 1

Results of statistical analyses.

Independent variables	MANOVA	ANOVA			
		ES	MU	EO	RA
Height	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Configuration	**<0.001**	**<0.001**	**<0.001**	**<0001**	**0.012**
Height × Configuration	0.086	N/A	N/A	N/A	N/A

Note: Bold values indicate significant results.