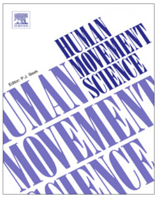
Human Movement Science 40 (2015) 315–325

Contents lists available at ScienceDirect

Human Movement Science

journal homepage: www.elsevier.com/locate/humov



Changes in muscular activity and lumbosacral kinematics in response to handling objects of unknown mass magnitude

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ARTICLE INFO

PsycINFO classification:
3610
4010
3670

Keywords:
Load knowledge
Lifting
Electromyography
Spine movement

ABSTRACT

The aim of this study was to evaluate the main and interaction effects of mass knowledge and mass magnitude on trunk muscular activity and lumbosacral kinematics. Eighteen participants performed symmetric box lifts of three different mass magnitudes (1.1 kg, 5 kg, 15 kg) under known and unknown mass knowledge conditions. Outcome measures were normalized peak electromyography of four trunk muscles in addition to three dimensional lumbosacral angles and acceleration. The results indicated that three out of four muscles exhibited significantly greater activity when handling unknown masses ($p < .05$). Meanwhile, only sagittal angular acceleration was significantly higher when handling unknown masses ($115.6 \pm 42.7°/s^2$) compared to known masses ($109.3 \pm 31.5°/s^2$). Similarly, the mass magnitude and mass knowledge interaction significantly impacted the same muscles along with the sagittal lumbosacral angle and angular acceleration ($p < .05$) with the greatest difference between knowledge conditions being consistently occurring under the 1.1 kg mass magnitude condition. Thus, under these conditions, it was concluded that mass magnitude has more impact than mass knowledge. However, handling objects of unknown mass magnitude could be hazardous, particularly when lifting light masses, in that they can

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http://dx.doi.org/10.1016/j.humov.2015.01.008

increase mechanical burden on the lumbosacral spine due to increased muscular exertion and acceleration.

1. Introduction

Manual materials handling such as lifting, pushing or carrying is a common activity for almost every human being. It can be performed either on a regular basis or irregularly depending upon the jobs demands. Lifting has been associated with an increased incidence of low back injuries (Coenen et al., 2014); it was shown to have a significant impact on trunk muscles activity (Ferguson, Marras, Burr, Davis, & Gupta, 2004). Unfortunately, handling objects without previous knowledge of their mass magnitude can be performed regularly in occupations such as luggage dispatching, refuse collection or mail distribution. In spite of a wealth of research exploring the different aspects of lifting maneuvers, very few studies were devoted to understanding the impact of mass knowledge on the musculoskeletal system.

Unexpected loading during manual materials handling can impact the trunk muscles that support the lifted objects as well as load the spinal tissues. Several studies tested how expectation during sudden loading influenced trunk muscle responses (Grondin & Potvin, 2009; Hwang, Lee, Park, & Kwon, 2008; Marras, Rangarajulu, & Lavender, 1987; Mawston, McNair, & Boocock, 2007). However, few studies investigated the impact of handling objects without prior knowledge of their mass, which can be a common daily occurrence.

Irrespective of which technique is preferred to handle an object, its proper execution requires precise neuromuscular coordination. This, in turn, requires a lifting strategy that considers and adapts to the magnitude and the size of the object mass (Kingma, Van Dieen, & Toussaint, 2005). Sometimes subjects can predict the needed strategy based on their previous experiences (Marras et al., 2006). However, other times this is not possible due to a lack of experience or when the load magnitude is unknown. When making inaccurate predictions about an object's mass magnitude, the trunk can adopt an inappropriate kinematic profile (Heiss, Shields, & Yack, 2002; Kotowski, Davis, & Shockley, 2007), which can be uncontrolled requiring stabilization (Butler, Andersson, Trafimow, Schipplein, & Andriacchi, 1993), achieved through trunk muscles co-contraction (Brown & McGill, 2010; Grondin & Potvin, 2009).

Handling objects of unknown mass can result in either mass overestimation or underestimation that can result in adverse effects. Subjects may lose their balance and suffer a fall or postural reactions required to regain balance could place the low back at risk of tissue damage (Commissaris & Toussaint, 1997; van der Burg, van Dieen, & Toussaint, 2000). Studies exploring trunk muscles response to lifting unknown masses are scarce. One study found that lifting an unknown mass increased back muscle activation by 10% compared to the known condition (de Looze et al., 2000). However, these authors used only two mass magnitudes (6.5 and 16.5 kg), which may have limited the options and made it easier for the subjects to expect the correct mass magnitude. Another study reported a sudden burst of abdominal muscle activity but only immediately after picking up a box of underestimated mass (van der Burg et al., 2000). Another recent study found a delayed increase in the trunk muscle activity when handling an object of underestimated mass. However, these authors used light masses (1 and 4 kg) and the subjects performed unilateral lifts in seated positions, which would limit the applicability of the results (Watanabe et al., 2013). Lack of knowledge about the center of mass of the lifted object did not appear to affect back muscles activities, although the position of center of mass impacted the Erector Spinae peak muscle activity (Meyers & Keir, 2003).

Trunk kinematics can also be influenced by mass knowledge as reported in a limited number of studies (Butler et al., 1993; Kotowski et al., 2007). These studies suggest that the effect of handling an unknown mass, although significant, was of too small a magnitude to be of clinical significance

(Kotowski et al., 2007). However, compared to a heavy mass (15.3 kg), lifting a very light unknown mass (empty box) significantly impacted trunk velocity leading to jerkiness (Butler et al., 1993). Also, handling an underestimated object mass did not affect maximum lumbar angle (van der Burg & van Dieen, 2001), whereas, overestimation of an object mass caused faster trunk extensions, that greatly disturbed balance and required protective stepping (Commissaris & Toussaint, 1997).

Finally, object mass magnitude has been shown to significantly impact trunk kinematics and muscle activity (Allread, Marras, & Parnianpour, 1996; Buseck, Schipplein, Andersson, & Andriacchi, 1988; Davis & Marras, 2000; Granata & Marras, 1995; Yoon, Shiekhzadeh, & Nordin, 2012). However, the interactive influence of changes in load mass and load mass knowledge upon the musculoskeletal system and the subsequent risk of injury is largely unknown. Therefore, the aim of the current study was to better understand the interaction effect of mass knowledge and mass magnitude on lumbosacral kinematics and myoelectric activity of trunk muscles during lifting.

2. Methods

2.1. Sample

A sample size of 18 subjects (4 females and 14 males) was recruited with a mean (standard deviation, SD) age of 26.8 (4.9) years, body mass of 73.3 (14.8) kg, and height of 176.5 (9.6) cm. Subjects were healthy, non-athletic individuals without previous history of low back musculoskeletal problems or manual materials handling job experience in the year prior to joining the study. All subjects signed a consent form approved by the Institutional Review Board of the Ohio State University.

2.2. Study design

A repeated-measures, within subject experimental design was used in this study. Subjects performed symmetrical lifting trials with different object masses and different levels of mass knowledge. The independent variables consisted of object mass knowledge which had two levels: known mass and unknown mass, and mass magnitude which had three levels: 1.1 kg, 5 kg and 15 kg. The total number of experimental conditions was $2 \times 3 = 6$. Three repetitions were performed for each condition resulting in a total of 18 lifts/subject. Randomization of different lifting conditions was used to control for the carry-over effect.

Dependent variables consisted of the peak normalized electromyographic (EMG) activity of eight trunk muscles and lumbosacral kinematics (including absolute values of peak angular position and angular acceleration in the sagittal, frontal and transverse planes).

2.3. Instrumentation

Surface EMG data were collected using a Model 12 Neuradata Acquisition System (Grass Technologies West Warwick, RI, USA). Surface bipolar electrodes (Ag/AgCI), with a 2 cm between-electrode distance, were placed along muscle fibers over the targeted muscles. EMG data were collected at a 1000 Hz frequency. Signals were high-pass filtered at 30 Hz, low-pass filtered at 500 Hz with a notch filter at 60 Hz. EMG data were rectified and averaged using a 40 ms sliding window filter. The signal was normalized relative to values collected during maximum voluntary isometric contractions (MVIC).

A Lumbar Motion Monitor (LMM) (Biodynamics Solutions, Columbus, OH, USA) was used to measure movement characteristics of the lumbar spine. This device is a triaxial exoskeleton of the spine that can measure instantaneous changes in lumbar angular position, lumbar angular velocity, and acceleration in a three dimensional space. LMM validity, accuracy and reliability has been reported previously (Marras, Fathallah, Miller, Davis, & Mirka, 1992).

All data were recorded and synchronized using a customized Laboratory Information Management System (LIMS) software that stored it in a computer through a PCI-6031E Data Acquisition A/D recorder (National Instruments, Austin, TX, USA).

2.4. Procedures

Following a brief explanation of the study procedures, participant preparation was begun. EMG electrodes were placed over the muscles of interest. Activity from four pairs (right and left) of trunk muscles was recorded including the Erector Spinae (ES), Internal Oblique (IO), Rectus Abdominus (RA) and External Oblique (EO) muscles. After hair removal and skin preparation to reduce skin impedance (below 100 KΩ), EMG electrodes were placed at standard locations reported previously (Mirka & Marras, 1993).

After an EMG signal check for baseline noise, participants were moved to a structure that restricted the pelvis and shoulders for performance of the MVICs of the trunk muscles, while in a standing posture. MVIC EMG data were used for normalization of the EMG data recorded during the experimental lifting trials. Four MVCs were performed in different directions including Flexion, Extension (with the trunk flexed 20°), Right Twisting and Left Twisting. Participants were then removed from the MVIC structure and the LMM was mounted on their back.

Lifting tasks consisted of symmetric lifting of a box to the chest level. The box was placed on a shelf at the subject's knee level, 45 cm in front of the subject's heels. Three identical boxes with different masses were used. After each lift, participants were instructed to turn around so that their back is facing the box and close their eyes while the examiner changed the box with the new mass for the following lifting trial. Familiarization lifting trials, of different masses, were performed prior to the actual data collection.

Participants were instructed to assume a natural standing posture for the lifting maneuver and choose a comfortable between-feet distance. The zero flexion angle was defined as the lumbosacral flexion angle in the erect standing prior to bending forward to make a lift. Foot placement was marked on the floor to ensure repeatability between lifting trials. Participants were instructed to reach for the box and lift it up to the chest level in a natural way. During the known mass conditions, participants were informed about the mass of the box prior to the lift.

2.5. Statistical analysis

The independent variables consisted of mass knowledge at two levels: known mass and unknown mass conditions, and mass magnitude at three levels: 1.1 kg, 5 kg and 15 kg. The mean normalized peak EMG data of the muscles of interest and the three dimensional lumbosacral angles and acceleration were the dependent variables. Descriptive statistics (mean and SD) of all dependent variables were computed as a function of all the experimental conditions. Repeated measures analysis of variance (ANOVA) was used to test the main and interaction effects of the independent variables. All significant effects were further analyzed using Tukey's Post-hoc test. For significant interaction effects (EMG and sagittal position and acceleration), pairwise comparisons were performed to independently test the effects of mass knowledge at each mass level. Results were considered significant at $\alpha < .05$.

3. Results

3.1. Trunk muscles activity

Mass knowledge significantly impacted peak activity of the trunk muscles except that of the RA ($p = .074$) muscle. Meanwhile, mass magnitude significantly affected ($p = .001$) all the trunk muscles (Table 2). On average, lifting trials in which participants handled unknown masses resulted in higher peak EMG values, for all muscles, compared to the known mass lifts (Table 1). As expected, EMG values varied relative to the mass magnitude lifted, regardless of the knowledge condition. EMG levels increased with increasing magnitude of mass handled. However, RA and EO muscles exhibited different behaviors, particularly when handling masses of small magnitude. Post-hoc test results indicated that the EMG activity of the different trunk muscles resulting from different mass conditions were significantly different from each other, except for the 1.1 kg and 5 kg masses where the RA and EO muscles were not significantly different. The mass magnitude and mass knowledge interaction

Table 1

Mean (SD) of the normalized EMG (%) and lumbosacral kinematics (position in degrees and acceleration in °/s^2) as a function of mass knowledge and mass magnitude main effect.

	Mass knowledge		Mass magnitude		
	Known	Unknown	1.1 kg	5 kg	15 kg
IO	**26.0** (**16**)	**28.7** (**16**)	**18.7** (**10**)*	**22.8** (**10**)**	**40.7** (**18**)***
EO	**4.6** (**3**)	**5.2** (**3**)	**4.0** (**3**)	**4.1** (**3**)**	**6.5** (**3**)***
RA	3.5 (3)	3.9 (4)	**3.2** (**3**)	**3.1** (**2**)**	**4.8** (**5**)***
ES	**36.3** (**17**)	**38.3** (**16**)	**26.2** (**9**)*	**32.4** (**10**)**	**53.5** (**15**)***
Sag. Pos.	27.7 (6.3)	28.08 (6.2)	**26.86** (**6.3**)*	**27.58** (**6.1**)**	**29.21** (**6.1**)***
Lat. Pos.	0.37 (2.8)	0.381 (2.8)	**0.04** (**2.7**)	**0.24** (**2.7**)	**0.85** (**2.8**)***
Tws. Pos.	0.20 (2.9)	0.299 (2.8)	0.15 (2.6)	0.11 (2.9)	0.49 (2.9)
Sag. Acc.	**109.3** (**31.5**)	**115.6** (**42.7**)	**135.14** (**40.1**)*	**112.45** (**30.8**)**	**89.70** (**25.9**)***
Lat. Acc.	13.97 (7.6)	14.48 (10.1)	13.77 (10.7)	13.38 (7.5)**	15.54 (8.1)
Tws. Acc.	11.09 (6.6)	11.67 (7.6)	10.97 (7.3)	11.12 (6.9)	12.06 (7.1)

Bold values indicate significant main effects of mass knowledge or mass magnitude at $p < .05$.

IO: Internal Oblique, EO: External Oblique, RA: Rectus Abdominus, ES: Erector Spinae, Sag. Pos.: sagittal position, Lat. Pos.: Lateral Position, Tws. Pos.: Twisting Position, Sag Acc.: sagittal acceleration, Lat. Acc.: Lateral Acceleration, Tws. Acc.: Twisting Acceleration.

* Indicates significant difference between 1.1 kg and 5 kg masses ($p < .05$).

** Indicates significant difference between 5 kg and 15 kg masses ($p < .05$).

*** Indicates significant difference between 1.1 kg and 15 kg masses ($p < .05$).

significantly affected normalized EMG data. Only the RA muscle ($p = .25$) was the exception to this trend. The results indicated that its activity was not significantly affected by the interaction between mass knowledge and mass magnitude (Table 2).

As expected, the highest EMG readings occurred when handling a heavy box of unknown mass magnitude, whereas the lowest readings were recorded when handling a light box of known mass magnitude (Fig. 1). Moreover, the mean difference in EMG data as a function of mass knowledge was always greater when handling light masses than heavy masses. Simple effects analysis indicated that mass knowledge had a significant effect for all muscles at 1.1 kg and only for IO at 5 kg, while it did not significantly affect any of the muscles at 15 kg (Table 2). Significant differences ranged between 15% (for ES, $p = .041$)) up to 28% (for EO, $p = .022$) for the 1.1 kg box, while for the 15 kg box, a maximum (non-significant) difference of only 4% (for RA, $p = .523$) was obtained.

Table 2

Summary of statistically significant p values for different conditions.

	Main and interaction effects			Post-hoc test		
	MK	MM	MK * MM	1.1 kg	5 kg	15 kg
IO	**0.001**	**0.001**	**0.025**	**0.034**	**0.010**	0.342
EO	**0.001**	**0.001**	**0.010**	**0.022**	0.127	0.831
RA	0.074	**0.001**	0.250	**0.036**	0.210	0.523
ES	**0.001**	**0.001**	**0.010**	**0.041**	0.130	0.421
Sag. Pos.	0.182	**0.001**	**0.002**	**0.043**	0.862	0.238
Lat. Pos.	0.980	**0.001**	0.411	–	–	–
Tws. Pos.	0.514	0.236	0.447	–	–	–
Sag. Acc.	**0.016**	**0.001**	**0.001**	**0.020**	0.137	0.070
Lat. Acc.	0.181	0.924	0.059	–	–	–
Tws. Acc.	0.248	0.224	0.308	–	–	–

Bold numbers indicate significant effect at $p < .05$. MK: mass knowledge, MM: mass magnitude, IO: Internal Oblique, EO: External Oblique, RA: Rectus Abdominus, ES: Erector Spinae, Sag. Pos.: sagittal position, Lat. Pos.: Lateral Position, Tws. Pos.: Twisting Position, Sag Acc.: sagittal acceleration, Lat. Acc.: Lateral Acceleration, Tws. Acc.: Twisting Acceleration. Post-hoc test: simple effects analysis of different mass magnitudes as a function of knowledge conditions (known vs. unknown).

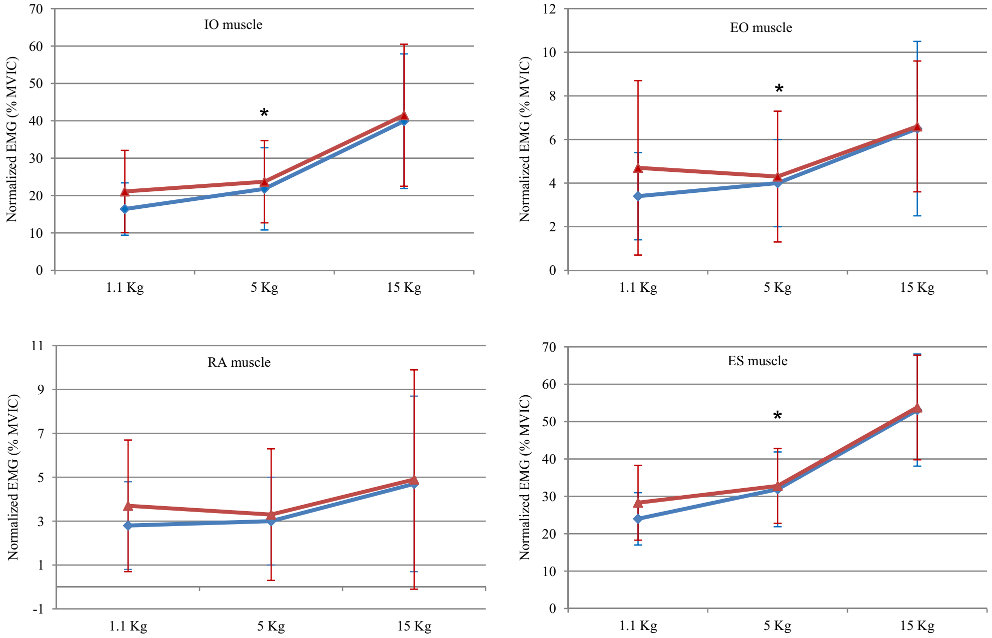

Fig. 1. Normalized EMG values (average peak) of the different muscles as a function of the mass knowledge and mass magnitude interaction. IO: Internal Oblique, EO: External Oblique, RA: Rectus Abdominus, ES: Erector Spinae. Blue line for known mass conditions. Red line for unknown mass conditions. *Indicates significant interaction effect at $p < .05$. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

3.2. Trunk kinematics

Mass knowledge did not affect lumbosacral angles, whereas mass magnitude significantly affected sagittal and lateral lumbosacral angles ($p = .001$) (Table 2). Furthermore, only sagittal lumbosacral acceleration was significantly impacted by mass magnitude ($p = .001$) and mass knowledge ($p = .016$). Higher acceleration values were recorded under the unknown mass conditions (115.6°/s^2) and when handling light masses (135.14°/s^2), compared to the known mass conditions (109.3°/s^2) and handling heavy masses (89.7°/s^2) (Table 1).

Mass knowledge seemed to interact with mass magnitude to significantly affect some of the lumbosacral kinematic measurements. As shown in Figs. 2 and 3, sagittal lumbosacral angle ($p = .002$), and acceleration ($p = .001$) were significantly impacted by the interaction between mass knowledge and mass magnitude, whereas other kinematic measurements were not. Pairwise comparisons (Table 2) showed that mass knowledge significantly impacted sagittal lumbosacral angle ($p = .043$) and acceleration ($p = .02$), but only when handling the 1.1 kg box.

Lumbosacral flexion angle measurements increased with increasing mass magnitude (Fig. 2). The greatest sagittal lumbosacral angle (29.52°) was recorded when lifting a 15 kg box of known mass. In contrast, the greatest sagittal angular acceleration (145.71°/s^2) was obtained during the 1.1 kg lift of unknown mass, while the lowest angular acceleration (86.28°/s^2) was recorded during lifting a 15 kg box of unknown mass. Handling a light 1.1 kg box under the unknown mass condition significantly increased sagittal position and acceleration by about 4.4% and 14.5%, respectively, compared to handling the same mass under the known mass condition.

4. Discussion

This study demonstrated that all trunk muscle activities were significantly affected by changes in mass magnitude. Furthermore, all trunk muscles, except the RA muscle, were significantly impacted

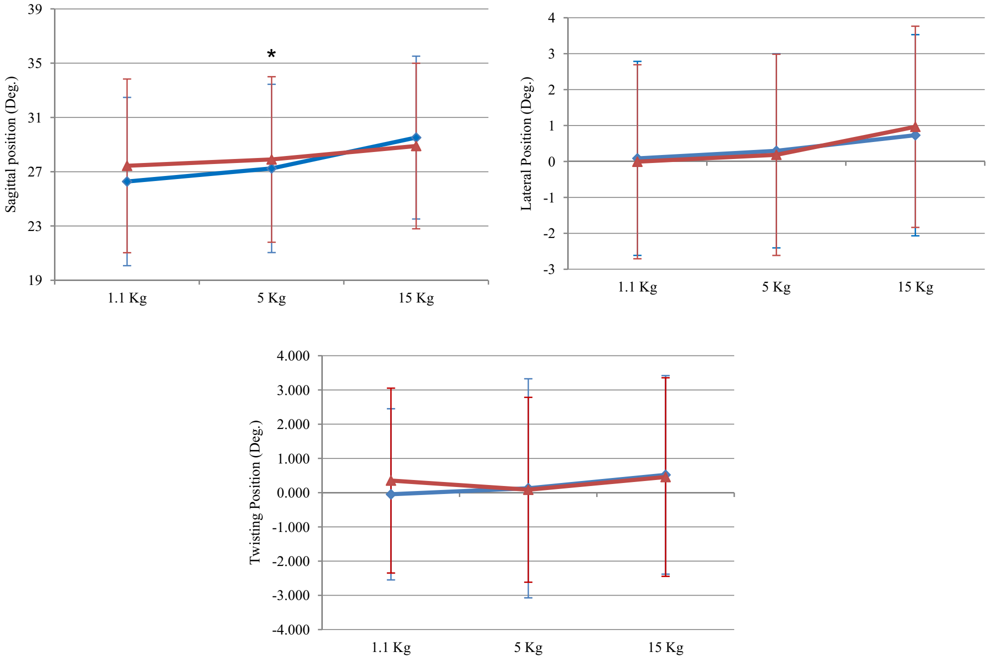

Fig. 2. Lumbosacral position angles (average peak) as a function of the mass knowledge and mass magnitude interaction. Blue line for known mass conditions. Red line for unknown mass conditions. *Indicates significant interaction effect at $p < .05$. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

by lack of mass knowledge. Similarly, the interaction of mass magnitude and mass knowledge impacted all muscles activities except the RA muscle. Multiple studies have reached a similar conclusion regarding mass magnitude (Anton, Rosecrance, Gerr, Merlino, & Cook, 2005; Chen, Lei, Ding, & Wang, 2004; Davis & Marras, 2000; Marras & Mirka, 1992). ES and IO muscles had the highest EMG activity and were more responsive to increasing mass magnitude, while RA and EO muscles were much less responsive. This is in agreement with previous studies that reported the highest EMG activity from ES and IO muscles during lifting (Fathallah, Marras, & Parnianpour, 1997). One would expect different activity levels for back and abdominal trunk muscles since back muscles are the primary force generators for extension under these conditions, whereas abdominal muscles act to increase spinal stability and control.

Overall, a trend was noted for all muscles in that more muscular activity was observed when handling unknown masses. Typically, a subject would prepare to handle objects by contracting his/her muscles with enough force needed to balance the external load lifted (de Looze et al., 2000). However, in the case of absence of mass knowledge, muscular preparation might be poorly anticipated and objects could be interpreted as lighter or heavier than the actual mass. Both conditions have been shown to increase the trunk muscles' activities (de Looze et al., 2000; van der Burg & van Dieen, 2001; van der Burg et al., 2000) with more profound effects reported when lifting an unexpectedly light mass, which we also observed.

The changes in EMG in response to the interaction of the mass knowledge and mass magnitude interaction indicated that greater differences were evident, between known and unknown lifting trials, for the light mass (1.1 kg) magnitude compared to the heaviest mass condition (15 kg). Thus, it appears that muscular overexertion could occur as a result of over or underestimation of mass magnitude.

In the case of overestimation of a mass, which typically occurs with light mass magnitudes, the subject would be expected to prepare the muscles for handling a lighter than expected mass. Over preparation is achieved through increasing activity of antagonistic trunk muscles that could exert

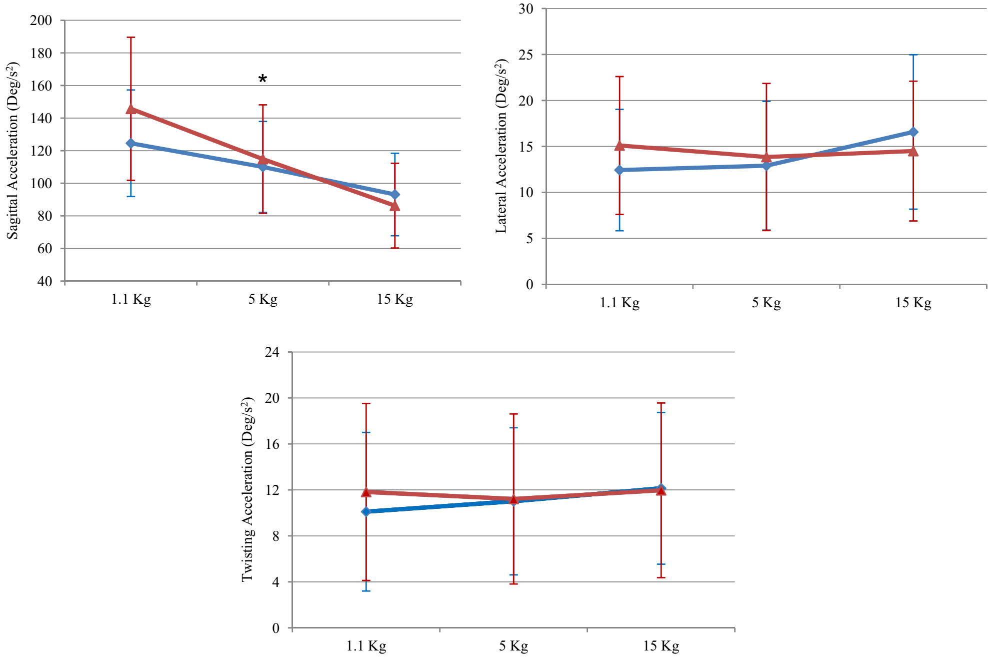

Fig. 3. Lumbosacral acceleration (average peak) as a function of the mass knowledge and mass magnitude interaction. Blue line for known mass conditions. Red line for unknown mass conditions. *Indicates significant interaction effect at $p < .05$. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

unnecessarily high forces. This could increase loading on the spine (Farrag, Elsayed, El-Sayyad, & Marras, 2014), thus, increasing the potential for back injury. Unnecessary over exertion of back muscles can cause an over-correction of angular and linear momentum of the trunk leading to loss of balance (Commissaris & Toussaint, 1997), which was observed in a number of our participants. This was evidenced by the significantly higher sagittal trunk acceleration recorded when handling the unknown, but light mass (1.1 kg). This has been reported previously to be associated with increased trunk muscles activity (Fathallah et al., 1997; Kim & Marras, 1987). Hence, in order to overcome a balance disturbance due to an uncontrolled trunk movement, trunk muscles would cocontract at even greater levels to control trunk movement, stabilize the spine and regain balance. The end result would be greater muscle activities when lifting the 1.1 kg box of unknown mass, relative to the known condition, and this is indeed what was found in this study.

The situation is markedly different in the case of underestimating the mass magnitude, as was the case when lifting the 15 kg box while expecting a lighter load. Unknown lifts resulted in minimally higher muscle activity. However, we suspect that this happened late in the response just after the subjects realized that they had underestimated the mass magnitude. Additionally, a heavier than expected box can create a forward moment of the trunk once the subject starts to lift since the level of muscular exertion may not be sufficient to lift the load and this situation could disturb balance and stability (Heiss et al., 2002). Thus, in order to overcome the forward moment, increased trunk muscle activity was necessary to create a counter moment (extensor moment) and extend the trunk upward.

Extensor trunk muscles (ES and IO) exhibited a significant change in their activity levels as a function of mass knowledge when handling light masses. The activity of the ES and the IO muscles increased by about 13% and 22%, respectively, during unknown mass lifting conditions. On initial consideration, this increase in EMG activity may seem biologically insignificant and of minimal clinical importance considering the magnitude of the EMG. However, our previous study reported that this level of EMG increase contributed to an increase in spine compression of about 240 N per lift

(Farrag et al., 2014). Such increases might overload the spinal tissues, particularly when considering cumulative loading over an entire working day. In addition, these effects might be magnified and even more dangerous under different real-world lifting conditions.

In this study, mass magnitude clearly had a larger effect on trunk muscular activity than did mass knowledge. However, mass knowledge impacted the activity of most of the measured trunk muscles, particularly when handling objects of very low mass magnitude. These results have indicated that even anterior abdominal wall muscles, which typically are at very low levels of EMG activity, exhibited more activity during unknown lifts. These results agree with previous studies (Lavender, Marras, & Miller, 1993; Lavender et al., 1989; Marras et al., 1987) that reported elevated abdominal muscles activity in response to sudden unexpected loading.

Increased activity of abdominal muscles during unknown lifts could be a mechanism to maintain stability of the trunk in the frontal plane and prevent buckling sideways (Tesh, Dunn, & Evans, 1987). In addition, abdominal muscles coactivation levels increased to enhance spinal stiffness when handling an unstable load (van Dieen, Kingma, & van der Bug, 2003). The muscle responses may be a part of a ‘hip strategy’ that can be used to regain disturbed balance occurring with unknown lifts (Oddsson, Persson, Cresswell, & Thorstensson, 1999; van der Burg et al., 2000). Another explanation might involve a flexion response used to control the rapid uncontrolled upward movement of the trunk leading to loss of balance and increased risk of falling, particularly during lifting a box weighing less than expected. Sudden loss of balance can activate automatic neuromuscular reflexive responses intending to restore balance through forceful muscle contraction. In doing so, the risk of spinal injury could become greater.

In our study, the availability of knowledge about mass magnitude did not affect lumbosacral kinematics, except for sagittal acceleration. This finding agrees with the study conducted by Kotowski et al. (2007) who reported significant but still minimal differences of trunk kinematics as a function of lack of load knowledge. The insignificant lumbosacral angular changes reported in our study, as a function of mass knowledge, indicated that mass knowledge does not significantly influence how subjects approach an object of unknown mass magnitude. Its effect appears to be minimal, otherwise subjects would have made significant postural adjustments before attempting the lift. On the other hand, mass knowledge had more impact on sagittal acceleration. This impact was more obvious with small mass magnitude. Higher sagittal acceleration measurements, observed during unknown light mass conditions, could be a reflection of the abrupt increase of the trunk upward movement, particularly with overestimation of box mass.

Handling heavy masses resulted in statistically significant, but minimally larger sagittal and lateral angles and significantly less sagittal acceleration. Higher sagittal acceleration was previously reported to be associated with handling light mass magnitudes (Allread et al., 1996; Davis & Marras, 2000; Ferguson, Marras, & Waters, 1992). Load origin height was proportional to the subject’s stature and located at knee level. This means that the significant increase of lumbosacral sagittal flexion could have been a postural response to increases in box mass lifted and not to changes in load origin height. It is worth mentioning that, although statistically significant, sagittal and lateral lumbosacral angle differences were of small magnitude ($<3^\circ$ for sagittal position and $<1^\circ$ for lateral bending and torsion) and most likely of limited functional significance.

Significantly different sagittal kinematic measures (position and acceleration) were also observed as a function of the mass knowledge and mass magnitude interaction. However, here again, the differences between the highest and lowest readings were of small magnitude ($<3^\circ$ for sagittal lumbosacral angle) and most likely of limited biomechanical significance. Greater differences were observed for sagittal acceleration with the highest value recorded during lifting a 1.1 kg box of unknown mass. Increased acceleration would result from increased lumbosacral moments, and correspondingly larger activity in the trunk muscles. This could increase the magnitude of spinal loads and, hence, the potential risk of injury (Davis, Marras, Heaney, Waters, & Gupta, 2002; Fathallah et al., 1997).

Several potential study limitations should also be acknowledged. First, the independent variables of mass magnitude and mass knowledge conditions were limited in terms of levels. For example, the mass knowledge variable had only the known and unknown mass conditions that may have limited its impact. The evaluation of more levels of mass knowledge such as known, overestimated unknown and underestimated unknown mass conditions might have revealed more significant and stronger interactions with other variables. Second, the symmetric lifting style used in the study limited trunk movement to the sagittal plane, which may have contributed to the insignificant response from the off-sagittal plane measures, such as lateral and twisting kinematics. Asymmetric lifting conditions might have resulted in much more prominent and potentially more risky effects. Third, gender was not considered in this study. Kotowski et al. (2007) indentified a gender-based impact on unknown mass lifting approach. Fourth, subjects were not seasoned workers with previous experience. Previous studies have reported that work experience had an impact on spinal loading characteristics (Marras et al., 2006).

5. Conclusion

Manually lifting objects, without prior knowledge of their mass magnitude, significantly impacted trunk muscular activity as well as sagittal angular lumbosacral acceleration. Under the conditions of this study, the effects of mass magnitude were larger than the effects of mass knowledge. Higher levels of trunk antagonistic muscular activity and greater sagittal accelerations were observed when handling light masses of unknown magnitude, and indicated poor anticipation of mass magnitudes. This resulted in mass overestimation and could result in unstable spine movements and/or balance loss. Ultimately we expect this could result in risk of injury to the lumbosacral tissues. These responses would be of concern during high frequency manual handling jobs that are becoming more common in work environments. It is recommended that mass magnitude should be clearly displayed on boxes when feasible and that workers should be trained as to how to safely and cautiously handle unknown masses.

Role of sponsor

None.

Conflict of interest

The authors declare that they have no conflict of interest.

Acknowledgements

The authors would like to thank Dr. Sue Ferguson for her valuable comments and suggestions. The authors also wish to thank Riley Splittstoesser, Gang Yang, and Greg Knapik for their assistance in data collection and analysis.

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