Comparison of three strategies of trunk support during asymmetric two-handed reach in standing

Caroline Damecour a,*, Mohammad Abdoli-Eramaki b, Ahmad Ghasempoor c, Joan Stevenson a

a School of Kinesiology and Health Studies, Queens University, Kingston, Ontario K7L 3N6, Canada
b School of Occupational and Public Health, Ryerson University, Toronto, Ontario M5B 2K3, Canada

Abstract
No trunk support (NTS) was compared to a lower trunk support (LTS) of leaning against a worktable and a dynamic upper trunk support (UTS) using postural kinematics, trunk extensor muscle activity and subjective rating of both comfort and effort. Ten females completed 3 repetitions where they lifted 0 and 5 kg load from a symmetrical position at hip-height to a 45° asymmetric position at: i) hip-height and ii) shoulder-height. Human motion capture showed trunk flexion decreased by 12° ± 10 with trunk support with hip-height reach. The table blocked axial rotation of the pelvis which was compensated by an additional 8° ± 6 rotation of the thoracic segment. Surface EMG of the lumbar erector spinae, contralateral to reach, showed the UTS to be almost twice as effective as the LTS with shoulder-height reach with a 30% ± 18 reduction. With hip-height reach, UTS resulted in a smaller reduction equal to 23% ± 27 while the LTS had no effect. Further investigation is needed to determine optimal performance parameters for trunk support with complex, dynamic trunk postures and whether altered kinematics arising from LTS have higher risk of upper back discomfort.

Keywords: Standing work; Trunk support; Reach; Low back; Ergonomics; Assistive device

1. Introduction

Whether it is reaching for a tool to assemble components, sorting materials from a conveyor, or using power hand tools such as a sander, grinder or polisher, forward reaching is a part of light and moderate stationary standing work when hand tools or material handling are involved. To increase reach distance, the trunk is recruited by bending and twisting toward the reach target. While the epidemiological association of low back disorders is mixed regarding mild trunk angles that are associated with longer reach distances, the high rate of change in biomechanical loading of the lumbar spine (Takahashi et al., 2006) indicates that ergonomic controls directed at reducing the amount of trunk recruitment would substantially reduce cumulative loading.

Reach envelopes and table heights are ergonomic strategies used to limit reach requirements but they can be difficult to implement especially with shared workspaces commonly found with conveyor and assembly line work. Trunk support is an alternate approach, with the objective being to lighten the load of the trunk rather than restrict trunk posture. Static forward-bent standing using an off-body, self-standing trunk support device was reported to reduce trunk extensor muscle activity by 60% (Damecour et al., 2010). However, these results apply to static, precision type work; it is unknown whether this type of trunk support is helpful with the dynamic trunk postures required for far reaching. The off-body device was a cushioned metal structure attached to a spring-loaded hinge joint. An on-body device reported by Abdoli-E et al. (2006) demonstrated 16% reduction in the average lumbar erector spinae (LES) muscle activity during dynamic lifting of a 5 kg load from the floor to a table; however, the self-standing device may be better suited to constrained standing workstations due to convenience of use.

Forward reaching to far distances differs from lifting in that trunk recruitment helps displace the shoulders forward rather than vertically. Without external support, any forward displacement of the body’s center of mass must remain within the base of support using a hip and/or ankle balance strategy. With the hip strategy, the lower body shifts away from the target (Lee and Lee, 2003; Holbein and Redfern, 1997), working against the reach action. With the ankle strategy, the body leans in the same direction as the reach; adding to the reach action but involves active muscle control by the

* Corresponding author. Tel.: +1 905 713 6202.
E-mail address: 7cmd2@queensu.ca (C. Damecour).
1 Abbreviations used in this article include: NTS – no trunk support, LTS – lower trunk support, UTS – upper trunk support, DTS – Dynamic Trunk Support device.
plantar flexor muscles. The off-body support would be advantageous for reach as it would not only support the trunk but also brace the pelvis in a neutral horizontal position, reducing the need for either a hip or ankle balance strategy.

In this study, trunk extensor muscle activity was compared when trunk support was used with complex, dynamic trunk postures which are associated with extended reach. The goal was to determine if trunk support lowers the postural work demands. Three trunk support conditions were tested: no trunk support (NTS), a lower trunk support (LTS) using an adjustable height worktable, and an upper trunk support (UTS) using an updated prototype version of the off-body device called the Dynamic Trunk Support (DTS) (Fig. 1). Testing involved a fixed reach distance as a way to determine if bracing changes trunk recruitment. Since both the LTS and UTS brace the pelvis in a forward position but only the UTS transfers a portion of the trunk weight above L4/L5, the change in back extensor muscle activity will be attributable to each effect.

2. Methods

2.1. Participants

Ten females with an average age of 30.5 ± 9.2 years and weight of 61.6 ± 10.3 kg participated in this study. Nine participants were right hand dominant. The methodology was approved by the University Ethics Committee. No recent musculoskeletal injuries were reported that would influence results and written informed consent was provided. Females were chosen because of the potential for increased discomfort under the chest support.

2.2. Set-up

A standing workstation was used for testing with the height of the table adjusted to hip-height. For all test conditions, participants stood in a comfortable lateral stride position with tape markings used to keep the foot positions constant throughout testing. For LTS, a frame for leaning was attached onto the tabletop so as the edge for leaning was approximately 30 mm below the anterior superior iliac spine on the pelvis and 40 mm in front of the participant. The wooden edge for leaning was 20 mm thick with no padding.

The DTS was fixed to the tabletop with the mechanical joint positioned at hip-height. This version of the DTS used a spring-loaded ball-joint mechanism for three-dimensional movement. The length of the post was adjusted so that the upper edge of the chest support was positioned 20 mm below the sternal notch. The resistance of the trunk support was the same for all participants but sufficiently low that forward bending continued to require eccentric muscle control from the back extensor muscles during the tasks.

2.3. Procedures

Two reach heights (hip and shoulder) and two loads (0 and 5 kg) were tested under three trunk support conditions (NTS, LTS and UTS) with the order of trunk support randomized. Practice time was provided prior to testing so that participants became accustomed to the trunk supports and reaching tasks. Participants were asked to start by lifting a 5 kg load held in two hands, reach forward and place the load on the marked target and return to upright standing with no load in hand. The sequence was repeated in the reverse order for the next repetition. This was repeated two more times for a total of six reaches. The pace was self-controlled with instruction to move at a slow comfortable pace. The reach targets were located .50–.55 m forward on a 45° angle to the left. The target heights were normalized to hip-height and shoulder-height. For trunk support conditions, participants were instructed to keep contact with the edge of the worktable or the DTS throughout the reach sequence.

Fig. 1. Three trunk support conditions: (A) no support, (B) lower trunk support, and (C) upper trunk support.
2.4. Equipment

An electromagnetic human motion capture system, Fastrak (Polhemus, Colchester, VT, USA), with a frequency of 70 Hz was used to continuously collect angular displacement (6 DOF) from sensors positioned over T9, L3, posterior left ilium and the right posterior mid thigh. Sensors were attached to the skin using spray adhesive and tape. Angular orientation was normalized to upright standing as recorded prior to each reach trial. Segment angles were extracted using Euler angles in the order of flexion, side flexion and rotation.

Surface electromyography (EMG) (Bortec Biomedical Ltd, AB, Canada) was used to record muscle activity with signals conditioned using a Bortec AMT8-channel differential amplifier (Bortec Biomedical Ltd, AB, Canada) with variable gains of 1000–5000 times, 10 G input impedance and CMMR of 115 dB. The EMG signals were digitally captured at 1024 Hz using a 12-bit A/D card (National Instruments, Austin, TX), band-passed at 20–450 Hz and then stored for processing using custom software (LabView 8.2.1, National Instruments, Austin, TX). Snap-on AgCl adhesive electrodes (Bortec Biomedical Ltd, AB, Canada) with a 3 cm inter-electrode distance were attached after the skin was abraded with alcohol. Muscle activity was recorded from the bilateral erector spinae at L4, gluteus maximus, and right hamstring. All raw EMG signals were rectified and low pass filtered using a 2nd order Butterworth filter with a cut off frequency of 2.7 Hz (Potvin et al., 1996). EMG was normalized to the peak value from three sequential maximal voluntary capacity (MVC) trials taken in prone lying using manual resistance.

Subjective ratings of low back discomfort, effort and pressure under the chest support were collected at the completion of each condition. Low back discomfort was rated using a 10 point visual analog scale (VAS) anchored by no discomfort and extreme discomfort. Effort was rated using a modified Borg scale. Pressure under the chest support, while leaning against the DTS, was rated using a 10 point VAS anchored by no pressure and extreme pressure.

2.5. Experimental design

A randomized, repeated measures design was used to test for trunk support with the additional independent variables of reach height and load. Dependent variables included trunk and thigh position at terminal reach (defined as the instantaneous posture corresponding to peak trunk flexion), muscle activity for the 90th percentile of the amplitude probability density function, and subjective response for: low back discomfort, effort, and pressure under the chest support of the DTS. The terminal trunk posture was described in terms of each segment: pelvis, lumbar and thoracic segment, and as a single segment with the inclusion of the three segments. The latter has been referenced as ‘total trunk’ and was calculated using the sensor overlying T9. The total trunk, thigh, and pelvis orientation are reported with a global reference; while the lumbar and thoracic segments are expressed relative to their proximal segment.

Prior to analysis of trunk support, the repeatability of the reach movement was assessed using intraclass correlation (ICC) (2,1) (Denegar and Ball, 1993). Both kinematic and EMG results were tested for a normal distribution using Kolmogorov–Smirnov (K–S) test and sphericity using Mauchly’s test. When Mauchly’s test was significant, the Greenhouse-Geisser correction was used. The effect of trunk support was tested using repeated measures analysis of variance (ANOVA), with paired contrasts used for post-hoc testing. The Friedman test was used as a non-parametric test for subjective findings. SPSS for Windows, release 17.0 (SPSS, Corporation, Chicago, IL, USA) was used for all statistical testing and statistical significance was accepted when $p < .05$.

3. Results

3.1. Preliminary statistical results

3.1.1. Kinematics

The ICC (2,1) of the total trunk and three segments for flexion, side flexion and rotation ranged from .47 to .97 with an average value of $0.82 \pm 0.10$ indicating good to excellent reliability between repetitions (Shrout and Fleiss, 1979). Values below .7 occurred four times, three of which occurred with rotation and UTS. This is consistent with subjective comments from some participants that the chest support tended to swing outwards and was sometimes difficult to control. The between-participant effect was significant for all trunk segments with all positional angles, $p < .005$, indicating that the terminal reach trunk posture differed between participants. Accordingly, the coefficients of variation were also high, ranging from 24 to 112%; higher values occurred with the lumbar and thoracic segments and with rotation. For all significant effects, the average change and standard deviation change are reported. The K–S test for thigh orientation in the sagittal plane was significant; visual inspection showed a strong central tendency.

A three-way repeated measures ANOVA of total trunk flexion looking for main effects from load, reach height and trunk support showed a main effect for: reach height, $F(1,9) = 58.0$, $p < .001$, trunk support, $F(2,18) = 6.0$, $p < .02$, with significant interaction between reach height and trunk support, $F(2,18) = 17.9$, $p < .001$, but no effect from load, $F(1,9) = .5$. The kinematic findings for load were then pooled. The mean difference in total trunk flexion between reach heights was 25.1°. Due to this large difference and for simplicity, statistical results are reported separately for reach height using one-way repeated measures ANOVA for trunk support.

3.1.2. Muscle activity

Only the LES muscle activity is reported since trunk support had no influence on either hamstring or gluteus maximus muscle activity. A three-way repeated measures ANOVA revealed a main effect for trunk support, $F(12,112) = 7.8$, $p < .005$, side of body, $F(1,9) = 16.5$, $p < .005$, but no effect for reach height, $F(1,9) = .0$, and no significant interactions. For convenience, the statistical results for LES muscle activity are also reported using one-way repeated measures ANOVA for trunk support.

3.2. Hip-height reach

3.2.1. Kinematics

At terminal reach, the total trunk orientation with NTS was complex with a combination of 52.1° ± 12.7° flexion, 28.5° ± 7.0° side flexion and 33.5° ± 16.4° rotation (Fig. 2A). Trunk support had a main effect on total trunk flexion with paired contrasts showing both supports being equally effective, $F_{(1TS)}(1,9) = 18.3$, $F_{(UTS)}(1,9) = 55.4$, $p < .01$, with a reduction equal to 12.2° ± 7.9° (Fig. 2B). With NTS, the flexion component of the terminal reach posture was multi-segmental with the pelvis contributing 38% ± 22%, lumbar 36% ± 24 and thoracic 27% ± 15. Trunk support had no main effect on either pelvis or lumbar segment flexion, but had a main effect on thoracic flexion. Paired contrasts showed this effect was from the UTS, $F(1,9) = 11.1$, $p < .01$, with a reduction equal to 5.9° ± 5.6. The orientation of the thigh in the sagittal plane was between 5° and 10° in a posterior direction for 90% of participants. This backwards’ orientation is consistent with a posterior shift of the pelvis that is associated with a hip balance strategy.
The rotational component of the terminal reach posture with NTS was also multi-segmental, with the pelvis contributing 32% ± 26, lumbar 11% ± 10 and thoracic 33% ± 25. The rotational angle of the thigh was within 4° ± 6.5 of pelvis rotation indicating a large portion of rotation originated in the foot and ankle joints. Unlike flexion, trunk support had no influence on total trunk rotation, however it had a main effect on pelvis rotation with paired contrasts showing that this effect was for the LTS only, $F(1,9) = 19.4, p < .005$. With LTS, pelvis rotation decreased by 8.8° ± 9.4° with three consequential changes: decreased total trunk rotation by 7.9° ± 11.7, however, this change was not significant; increased thoracic segment rotation by 6.7° ± 4.8 with paired contrasts showing this to be a significant effect, $F(1,9) = 19.4, p < .01$; and decreased thigh rotation by 9.3° ± 7.1 with paired contrasts showing this to be significant effect, $F(1,9) = 10.9, p < .005$. These changes demonstrate a trade-off in segmental contribution to rotation secondary to the LTS obstructing pelvis rotation with a loss of lower extremity involvement and an increase in thoracic rotation.

The side flexion component of the terminal reach posture with NTS was also multi-segmental with the pelvis contributing 35% ± 13, lumbar 40% ± 32 and thoracic 29% ± 21. Trunk support had no effect on total trunk side flexion but had a main effect on pelvis side flexion with paired contrasts showing that this effect was from the UTS, $F(1,9) = 16.7, p < .005$. Pelvis side flexion decreased by 4.9° ± 3.8 but no consequential changes were seen in the proximal segments in side flexion.

### 3.2.2. Muscle activity

Trunk support had no significant effect on the 90th percentile muscle activity of the left LES, only on the right side (Fig. 2C). Paired contrasts showed a significant effect for the UTS, $F(1,9) = 6.2, p < .05$, with a 5.8% ± 7.5 MVC decrease in muscle activity equal to a 23% ± 27 reduction.

### 3.2.3. Subjective findings

The average rating of low back discomfort with NTS was 3.5 ± 2.9. Trunk support had a significant effect, $\chi^2 = 118, p < .005$. With LTS, low back discomfort decreased by 1.8 ± 1.9 intervals. A larger reduction, equal to 3.5 ± 2.8 intervals, occurred for UTS with an actual rating equal to .7 ± 1.3. With NTS, the average rating of effort was 4.0 ± 2.4. Trunk support had a significant effect, $\chi^2 = 6.4, p < .05$; both supports were equally effective. Effort decreased by 1.6 ± 1.7 intervals with LTS and by 1.5 ± 1.4 intervals with UTS. The average perceived pressure under the chest support was 3.2 ± 2.4. Several participants reported an uncomfortable ‘digging’ sensation from the lateral edge of the chest support.

### 3.3. Shoulder-height reach

#### 3.3.1. Kinematics

The terminal reach trunk positioning with shoulder-height reach differed from hip-height reach. In comparison total trunk flexion was 53% ± 20 of that achieved with hip-height reach, while side flexion was 34% ± 33 and rotation was 17% ± 52 (Fig. 3A). As a result, the terminal reach trunk posture had a higher ratio of side flexion/rotation/flexion/rotation/flexion. Trunk support had no effect on total trunk flexion. With NTS, only 30% of participants had a thigh orientation consistent with a hip balance strategy. Similar to hip-height reach, forward flexion of the pelvis was not influenced by trunk support, but because the total trunk flexion was less with the shoulder-height, the pelvis contributed a larger amount to total trunk flexion, equal to 67% ± 38 (Fig. 3B). Trunk support also had no effect on lumbar or thoracic segment flexion.

Trunk support had a significant effect on axial rotation of the pelvis ($p < .01$) with paired contrasts showing that this effect was for the LTS only, $F(1,9) = 13.5, p = .005$. Rotation decreased by 11.1° ± 3.7. With NTS, the pelvis contributed 51% ± 23 to trunk rotation. With LTS, this ratio decreased to 1% ± 33. This blocking effect of pelvis rotation was also seen with hip-height reach with similar consequential results: decreased total trunk rotation by 7.3° ± 5.9, this time with a significant difference, $F(1,9) = 15.2, p < .005$, increased thoracic segment rotation by 8.3° ± 7.1 with paired contrasts showing this to be a significant effect, $F(1,9) = 13.5, p < .01$, and decreased thigh rotation by 9.3° ± 7.1 with a significant effect, $F(1,9) = 25.4, p < .005$.

Trunk support also had a main effect on pelvis side flexion, similar to hip-height reach. Paired contrasts revealed that this effect was largely from the UTS, $F(1,9) = 16.7, p < .005$, with a 2.5° ± 1.6 reduction, although the LTS also had a significant influence, $F(1,9) = 24.0, p = .001$. With LTS, pelvis side flexion decreased by

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Fig. 2. Hip-height reach results for (A) total trunk orientation angles, (B) segment orientation angles, and (C) LES muscle activity at 90th percentile; all adjusted for repeated measures.
1.3° ± 3.3. The change in pelvis side flexion was not reflected in any of the proximal trunk segments, nor total trunk side flexion.

3.3.2. Muscle activity

Paired contrasts revealed that both trunk supports were equally effective on the left side, F(LTS)(1,9) = 9.3, F(UTS)(1,9) = 9.2, p < .05, with a reduction of 4.3% MVC ± 4.3 equal to a 27% ± 18 reduction (Fig. 3C). On the right side, both trunk supports had a significant influence, F(LTS)(1,9) = 5.8, F(UTS)(1,9) = 11.5, p < .05, with the UTS having a significantly larger effect, F(1,9) = 6.3, p < .05. With LTS, muscle activity decreased by 3.5%MVC ± 4.5, equal to a 16% ± 22 reduction, while UTS decreased muscle activity by 6.3%MVC ± 5.9, equal to a 30% ± 18 reduction.

3.3.3. Subjective findings

With NTS, the average rating of discomfort was 2.6 ± 2.5. This differed from hip-height reach by .9 ± 1.7 intervals. Trunk support had a significant effect, \( \chi^2 = 7.0, p < .05 \); both supports were equally effective. Discomfort decreased by 1.1 ± 1.4 intervals with LTS, and 1.6 ± 2.5 intervals with UTS. While the change for UTS was half compared to hip-height reach, the actual ratings were similar between reach heights. With NTS, perceived effort was rated an average 3.5 ± 1.7, similar to hip-height reach. Trunk support had a significant effect, \( \chi^2 = 7.0, p < .05 \); both supports were equally effective. Effort decreased by 1.5 ± 1.4 intervals with LTS and by 1.6 ± 1.1 intervals with UTS. These results are similar to those for hip-height reach. The average perception of pressure through the ribcage was 3.0 ± 2.4, also similar to hip-height reach.

4. Discussion

With NTS, the flexion component of the terminal reach trunk posture differed by more than half between reach heights. This was consistent with the methodology since the forward reach distance was not adjusted to account for a greater contribution from the outstretched arm to the forward reach distance with shoulder-height reach. Zhang and Chaffin (1997) reported similar findings with sitting reach. Both the LES muscle activity and the subjective response were insensitive to the difference in the terminal reach posture, and the curvilinear relationship between trunk flexion and LES muscle activity may be partially responsible. Sakamoto and Swie (2003) reported that the peak LES muscle activity corresponded to 45° flexion with forward bending, while the decline in muscle activity started at 60° flexion. With NTS and hip-height reach, 70% of participants had a trunk flexion angle greater than 45°, beyond the peak value, while the average trunk flexion with shoulder-height reach was 23° or below the peak value.

The complex trunk posture may also explain the similarity in LES muscle activity under NTS if the LES muscle activity response was more sensitive to side flexion and/or rotation than flexion. Under these reach conditions, the differences in the side flexion and rotation components were much smaller than flexion, especially rotation which differed by less than 25%. Posture asymmetry influenced LES muscle activity since differences were seen between the left and right side. In the workplace, trunk asymmetry may be more important to correct than flexion angle but further study is needed.

A hip balance strategy was not evident for shoulder-height reach with NTS. The lack of a hip strategy is consistent with the model of dynamic posture control proposed by Stapley et al. (1999) where the horizontal trunk position shifts toward the reach target as long as postural balance is maintained. With shoulder-height reach, the average total trunk flexion was less than 23°, corresponding to a small displacement for the center of mass and, therefore, there is less need for a hip balance strategy. This finding may vary under other conditions since both individual and work factors have been shown to influence displacement of the center of mass with reach including: age (Row and Cavanagh, 2007; Kozak et al, 2003), reach distance (Stapley et al., 1999; Kaminski et al, 1995; Tyler and Karst, 2004), load magnitude (Gagnon and Smyth, 1991), speed of motion (Lee and Lee, 2003), and foot placement (Holbein and Chaffin, 1997).

Trunk support influenced the LES muscle activity with both supports effective for shoulder-height reach, but only the UTS with hip-height reach. Since the effect of bracing on the use of a hip balance strategy only occurred for hip-height reach; bracing had no translation to muscle activity. This is consistent with the findings for NTS and the two reach heights. It is unknown if this finding would also occur with smaller degrees of trunk posture asymmetry.
Since the LES response to LTS was not related to bracing, the LTS must have acted through a different mechanism, probably secondary to the consequential changes arising from the obstruction of the pelvis rotating. Both the reduction in total trunk rotation and increase in thoracic segment rotation would act to reduce LES work demands by decreasing rotational torque and shifting biomechanical loading away from the LES to passive structures (Marras and Davis, 1998; Pope et al., 1986; McGill, 1992). Since these changes occurred equally for both reach heights, but the LTS was only effective with shoulder-height reach, the mechanism of how the LTS influenced LES muscle activity is still unknown. Trunk flexion, however, appears to be a confounding factor.

Since the LTS did not produce any gain by way of bracing and the UTS did not alter trunk rotation, the change in muscle activity with UTS should be fully attributable to weight transfer. With UTS, right side LES muscle activity decreased by 23 and 30% with hip-and shoulder-height reach respectively indicating that UTS has potential benefit as an ergonomic strategy when ideal work heights and reach envelopes cannot be implemented. Subjectively, low back discomfort was reduced to 0 for 70% of participants with hip-height reach and 50% for shoulder-height reach after six reach repetitions when using the UTS. Although the short duration for testing limits the validity of these subjective findings, the results are encouraging and considered with the reduction in postural work demands, further product testing is reasonable. Interestingly, the variability in response indicates that UTS could be highly effective for some individuals but further investigation is needed to understand who would benefit. Prior to recommending the use of UTS in the workplace, longer term testing is required to determine how the posterior rib joints will respond to sustained low level compression from leaning. The trade-off between unloading the lower back with loading the posterior rib joints still remains to be determined.

The performance requirements of the UTS in terms of trunk motion were met with kinematic results showing the terminal trunk posture to be unchanged from the NTS condition with the exception of reduced thoracic segment flexion. This exception may be beneficial for individuals experiencing upper back discomfort while working, as a way of stiffening the segment. The performance requirements in terms of trunk support, however, do not appear to be fully met in two ways. First, the smaller effect on LES muscle activity with waist-height reach suggests that weight transfer may have diminished effectiveness as trunk flexion increases. Second, participants reported an unbalanced support between the rotation and forward flexion component of the reach motion. Based on findings for NTS at different reach heights, improving the balance of resistance between the three components of motion and increasing resistance at higher flexion angles may improve the performance of the UTS with complex trunk postures. A harness type attachment would overcome the limitations of the flat shape and unsecured nature of the chest support to support trunk motion into side flexion.

Since the LTS also reduced LES muscle activity, it is tempting to promote this type of trunk support but the results likely underestimated the change in postural work demands. Swie and Sakamoto (2004) reported that muscle activity was greater at L2 than L5 with trunk rotation and, therefore, this methodology would not capture increased muscle effort as part of the increased thoracic rotation. More concerning is that the height of contact tested for LTS was based on anatomical consideration for the absorption of the leaning reaction force rather than the recommended work heights. The tested height was lower than that recommended with light work (Grandjean, 1980). With a higher leaning contact height, the table is more likely to obstruct forward flexion as well as rotation of the pelvis, leading to greater compensatory changes in the upper back. Larière et al. (2000) reported a similar compensation by the thoracic spine with forward bending when there was lumbar spine stiffness secondary to low back pain. The positive subjective response for both discomfort and effort shows that trunk support is favored and most likely used in the workplace when there is a fixed worktable, ledge or equipment suitable for leaning against. Although bracing had no measurable change in LES muscle activity, it may have other benefits not captured in this methodology that may result in a discounting of the increased thoracic rotation. A longer term study may show different results.

Sources of variability in this study included: fixed amount of support leading to differences in proportion of weight transfer between participants, fixed forward reach distance leading to differences in the amount of trunk recruitment, anatomical differences in coupling and available spinal range of motion in the thoraco-lumbar region (Gercek et al., 2008) leading to differences in trunk segment recruitment. In addition to variability, the actual changes in kinematics and muscle activity between trunk support conditions were small and, therefore, sensitive to error arising from movement of sensors/electrodes or their leads independent of the segment. Despite these influences, trends in movement patterns were apparent, while changes in muscle activity were harder to understand. Investigation into the effectiveness was largely based on both hip and LES muscle activity, but given these results, further investigation should be carried out with additional EMG sites on the mid and lower back.

5. Conclusion

The UTS was the most effective trunk support to reduce dynamic postural work demands based on postural muscle activity, trunk posture and low back comfort during an asymmetric forward reaching task representative of light to moderate industrial work. Further investigation for optimal support delivery and suitable task conditions are needed followed by longer term use study prior to a widespread introduction of the DTS into workplace. Leaning against the LTS is of more immediate concern for those who work in constrained standing behind a worktable, ledge or equipment because of the altered trunk kinematics occurring with asymmetrical, long-distance reaching and possible association with increased risk of upper back pain.

Disclosure

The authors would like to disclose that Dr. Mohammad Abdoli-Eramaki is a principal investigator on an Ontario Partnership for Innovation and Commercialization grant designed to bring the Dynamic Trunk Support to market. Dr. Abdoli-Eramaki, through Ryerson University, has applied for a patent for the Dynamic Trunk Support.

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