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Designing ergonomic interventions for EMS workers—part II: Lateral transfers

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Abstract

The objective of the current work was to test ergonomic interventions aimed at reducing the low back musculoskeletal loads experienced by firefighters/paramedics (FFPs) providing emergency medical services (EMS) when performing lateral transfers between a bed and a stretcher or between a stretcher and a hospital gurney. The interventions, developed using focus groups, were a bridgeboard to reduce the frictional force resisting the lateral sliding of the patient, the use of rods along each side of the patient to facilitate the grasping and handling of the bedsheet on which the patient is typically transferred, and a single rod that, when rolled in the bedsheet, resulted in the task being changed from a lifting task to a pulling task. Eleven two-person teams laterally transferred a 75 kg dummy with each intervention between a bed and simulated stretcher. Two roles were defined. For the two-sided transfers, the FFP roles were termed "stretcher-side" and "bed-side." Surface electromyographic (EMG) data were collected from 8 trunk muscles from each participant along with spine kinematic data. Additionally, kinetic data were obtained for the FFP in the stretcher-side role. Trunk flexion moments and Erector Spinae activity were reduced for the FFP in the stretcher-side role when using the bridgeboard and the single rod both individually and in combination. The single rod reduced the Erector Spinae activity in the FFP who typically would have been on the bed. For FFPs in both roles the single rod increased Latissimus Dorsi activation relative to the standard bedsheet transfer condition, although, this effect was moderated when the single rod was used in combination with the bridgeboard. Ratings of perceived exertion also supported the use of the single rod relative to the corresponding control condition.

Keywords: LBD; EMS; Intervention; Firefighter; Back pain

1. Introduction

Musculoskeletal injuries consistently account for about half of all injuries to firefighter/paramedics (FFPs) engaged in emergency medical service (EMS) operations as well as to EMS workers in the private sector (Karter and Molis, 2004; Reichard and Jackson, 2004). These injuries result in lost work time, permanent disability, and high worker compensation costs (Karter and Molis, 2004; Walton et al., 2003). The economic burden of musculoskeletal injuries to workers in the US is estimated to be between $45 and $54 billion annually (IOM, 2001). In a recent analysis of 1343 firefighter worker compensation claims, the per-claim average worker's compensation cost for sprain/strain injuries was over 50 percent greater than for claims overall (Walton et al., 2003). The back was the primary body part affected.

As the prevalence of obesity in the general population increases, the risk for injury to EMS workers who handle and transport patients grows (CDC and NCHS, 2004). Many EMS runs begin with and nearly all EMS runs end with a lateral transfer task (Conrad et al., 2000), often from

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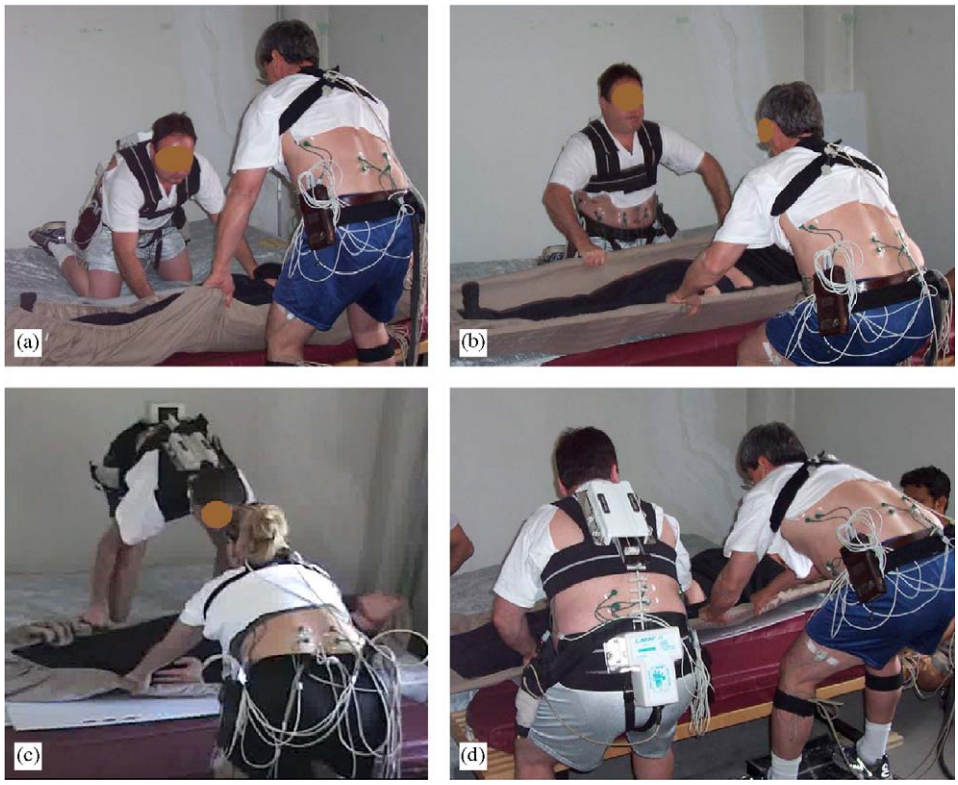

Fig. 1. Lateral transfers being performed with the bedsheet only (a), the dual rod (b), the bridgeboard (c), and the single rod (d). All the two-sided transfers were performed once with the person in the bedside role kneeling (a and b) and once with the person in the bedside role standing (c). With the single-rod transfers the "bedside" FFP was positioned alongside the stretcher-side FFP.

a bed to a stretcher at the patient's home and from the stretcher to the gurney at the hospital. Our previous research studying lateral transfer methods for transporting patients indicated that these are physically demanding tasks that result in large biomechanical loads while in awkward postures (Lavender et al., 2000a, b).

The purpose of this work was to evaluate ergonomic interventions aimed at reducing biomechanical loads on the back as patients are laterally transferred during EMS operations. FFPs frequently laterally transfer supine patients from the bed to a stretcher positioned alongside the bed and or from a stretcher to a hospital gurney. Typically, FFPs perform these lateral transfers, while positioned on each side of the patient, by lifting the patient with the existing bedsheet (Fig. 1a). The ergonomic interventions described in this paper have been developed to facilitate sliding the patient, as opposed to lifting, by making it easier to grasp the sheet or reduce the friction between the bedsheet and the surface below. It should be noted that the proposed interventions, if deemed successful in these evaluations, have the potential to be address the broader population of lateral patient transfer tasks that are performed in more traditional healthcare settings.

The specific ergonomic interventions were developed through a series of focus group discussions with FFPs (Conrad et al., in preparation). An industrial designer sketched drawings of the concepts suggested by the participants. During these discussions, the ergonomic challenges of using existing approaches and equipment were discussed and potential interventions were proposed for the ergonomic issues identified. Each of the interventions focused on assisting a two-person team. Within each team we identified two roles. Typically one FFP would kneel or stand on the bed (see Fig. 1). We termed this the "bed-side" role. The other FFP would usually stand in a stooped position on the far side of the stretcher in what we termed the "stretcher-side" role. While both FFPs lift, much of the horizontal movement of the patient is generated by the bedside FFP.

The first intervention was a pair of collapsible rods that were designed to facilitate the grasp of the bedsheet (Fig. 1b). By rolling the rods in the bedsheet, the sheet could be grasped such that patient can be wholly lifted from head to toe. The rods had a square cross-section (2.5 cm on a side) to prevent the sheet from slipping. The second intervention was a plastic bridgeboard that was designed to facilitate the sliding of the patient between the bed and the stretcher (Fig. 1c). The intent was that the bridgeboard be placed under the bedsheet adjacent to the patient and would provide a smooth transition between the bed and stretcher. The width of the bridgeboard was equal to the width of the stretcher mattress so that it could be easily transported and stored. The third intervention was a variation of the first intervention in which only one rod was used (Fig. 1d). With this intervention both FFPs worked from the stretcher-side and dragged the patient from the

bed to the stretcher. By rolling the bedsheet around the rod, the patient was transported evenly. Most importantly, this third intervention removed the FFP from the bed, which necessitated the task change from a lifting task to a pulling task. For each intervention the hypothesis tested was that the intervention reduced the muscle activity and trunk moments relative to the conventional bedsheet lateral transfer. A secondary research question asked whether it was better for the FFP on the bed to be standing or kneeling?

2. Methods

2.1. Experimental design

In this experiment, two-person teams of firefighters were recruited. Each team had one individual consistently perform the bedside role and one individual perform the stretcher-side role during the lateral transfers of the patient. For one-sided transfers, both FFPs were positioned along side the stretcher with one FFP at the level of the patient's chest and the other FFP at the level of the patient's thighs. For consistency of reporting, the term "bedside" is used throughout the paper to identify the bedside FFP even when this person moved to the stretcher-side.

The experiment used a randomized block design wherein each team served as a block and experienced all the interventions in a randomized sequence. There were six intervention conditions. These included using only the bedsheet (Control Condition), using two rods (Dual Rod), using the bridgeboard (Bridgeboard), using two rods in combination with the bridgeboard (Dual Road + Bridgeboard), using a single rod (Single Rod), and using a single rod in combination with the bridgeboard (Single Rod + Bridgeboard). Use of the three interventions and the control condition are shown in Fig. 1. Because we also were interested in determining if the posture for the bedside FFP should be one of kneeling or standing, each task in which the bedside FFP was actually on the bed (all transfers except those using the single rod) was repeated twice, once for each posture. Thus, this investigation required that each two-person team perform 10 lateral transfer tasks.

The dependent measures were the 90th percentile normalized surface electromyographic (EMG) signals from 8 trunk muscles recorded from each FFP, the 90th percentile three-dimensional torso motions and external three-dimensional trunk moments at L5/S1 for the stretcher-side FFP, and the peak three-dimensional motions from the bedside FFP.

2.2. Subjects

Eleven two-person teams of firefighter/paramedics (FFPs) were recruited from fire departments in the Chicago suburbs. All participants were employed fulltime as FFPs at their respective departments. Each participant signed an informed consent prior to participating in the study. Ten of the teams were comprised of two males. One team was comprised of two females. Assignment to a specific team was based on availability. In most cases the team members were from different departments or different shifts within the same department. The mean age, height, and weight of the subjects was 37 years (28–51 years), 1.80 m (1.63–1.89 m), and 96 kg (70–123 kg), respectively. On average the FFPs had 12 years of experience in the EMS component of the job (<1–25 years). None were experiencing low back pain at the time of the study.

2.3. Apparatus and instrumentation

In each transfer task a 75 kg dummy, similar to one used by the fire service for training exercises, was moved. The transfers were initiated with the dummy laying in a supine position on a bedsheet.

The bridgeboard had an ultra-smooth polyethylene surface. It measured 122 cm in length and 47 cm in width and was 0.5 cm thick. The stretcher was simulated using a wooden bench so as not to interfere with the magnetic motion capture system. The height of the bed and the simulated stretcher were increased to account for the height of the forceplates. The height of the stretcher was 54.6 cm above the forceplates. The bed was the same height as the top of the mattress on the stretcher.

The FFP located on the bed was instrumented with a Lumbar Motion Monitor (LMM) to quantify trunk postures. The FFP located next to the stretcher was instrumented with magnetic sensors (Accension) on each shank, each thigh, the pelvis (S1), and at the top of the thorax (T1). The FFP connected to the magnetic sensors stood on two Bertec forceplates.

Each FFP was connected to an eight channel telemetered EMG system (Noraxon). The RMS output from the Noraxon amplifiers was sampled along with the kinematic and kinetic data using InnSport^{TM} Motion Monitor data collection software at 120 Hz for 6 s.

2.4. Testing protocol

After reading and signing the informed consent documents and watching an instructional video that demonstrated how to use the experimental interventions, each member of the team was instrumented with disposable surface electrodes (Cleartrace^{TM} 1700-030) over the left and right Latissimus Dorsi (LATL and LATR), Erector Spinae (ERSL and ERSR), External Oblique (EXOL and EXOR) and Rectus Abdominus (RABL and RABR) at standard EMG collection sites as described by Marras (Marras, 1987). For the Erector Spinae, the electrodes were positioned approximately 5 cm lateral from the midline at the L3 level. The Latissimus Dorsi electrodes were positioned at the T7 level over the belly of the muscle, approximately 13–15 cm lateral from the midline. The

External Oblique electrodes were positioned at the level of the umbilicus and centered approximately halfway between the iliac crest and the anterior superior iliac spine at an angle of 45°. The Rectus Abdominus electrodes were placed just above the umbilicus approximately 2.5 cm lateral from the midline.

Prior to conducting the study, the subjects performed two types of maximal voluntary exertions to obtain maximal EMG signals for normalization purposes. In the trunk extension exertions subjects pulled up on a handle positioned at approximately mid thigh level. This resulted in a modest degree of spine flexion (~20°), similar to what we expected during the more strenuous points in the task. This task was repeated until maximal EMG values were obtained from both the Erector Spinae and Latissimus Dorsi muscles. The trunk flexion exertions were completed by connecting a cable between a chest harness and a reference frame apparatus (Lavender et al., 1992). These provided maximal signals from both sets of abdominal muscles. In reality, because of the weight of the dummy and the dynamic action of moving the dummy, often these "maximal" values were exceeded during the testing protocol. When this occurred, the maximal values were replaced with the highest observed EMG value.

Prior to collecting data for each exertion, the team members positioned themselves for the transfer according to the prescribed conditions. When two-sided transfers were performed, the FFP in the bedside role was told whether to stand or kneel for the upcoming transfer. For the single rod conditions the person in the bedside role came off the bed and stood next to the FFP in the stretcher-side role, alongside the patient's lower body. The team was in charge of coordinating the timing of each lateral transfer. During each task, the FFPs were encouraged to verbally communicate with each other as they typically would on the job. Immediately after the completion of each exertion the subjects were asked to provide a rating of perceived exertion using the Borg CR10 (Borg, 1998). The team was given a one to two minute rest period as the data were checked, and while members of our research team returned the dummy to the bed in preparation for the next experimental condition.

2.5. Data analysis

The EMG readings were normalized to relative maximum and resting levels. The kinetic and kinematic data for the FFP on the force plates were used in a linked-segment biomechanical model that calculated the L5/S1 moments by working up from the ground reaction force data through the ankles, knees, and hips. The model has been described previously (Lavender et al., 2000c). For the normalized EMG data, the three-dimensional moment data, and the stretcher-side kinematic data, 90th percentile values observed during each exertion were obtained using SAS software. For the FFP wearing the LMM in the bedside role, the peak values were exported from the LMM software.

The EMG data from each role (bedside and stretcher-side), the spine moment data from the stretcher-side FFP and the spine kinematic data were first analyzed using multivariate analyses of variance (MANOVA) in the SAS software. In these analyses the intervention effect was comprised of six levels: Bedsheet Only (control condition), Dual Rod, Bridgeboard, Dual Road + Bridgeboard, Single Rod, and Single Rod + Bridgeboard. Where multivariate analyses indicated significant ($p < .05$) intervention effects, univariate ANOVAs were run to identify the muscles, moments, or motion directions responsible for the multivariate effect. The REGWQ multiple comparison procedure (SAS, 1985) was used, as it controls the experiment-wise error rate, to make comparisons between the 6 levels of interventions analyzed. The ratings of perceived exertion data were analyzed using the SPSS (version 11.5) Kruskal–Wallis and the Mann–Whitney tests for ranked data.

3. Results

3.1. Standing versus kneeling on the bed

Pooling the data from all the trials in which a FFP was positioned on each side of the dummy indicated that there were no significant differences in the 90th percentile muscle recruitment levels between the standing and kneeling postures for either the stretcher-side or bedside FFPs. Hence, the EMG data for the standing and the kneeling trials were averaged in the analysis of the interventions for each role. Across the two-sided conditions sampled, the MANOVA results indicated that spine postures differed between the kneeling and standing trials for the FFP in the bedside role. Most notably, the mean forward flexion increased from 24–46° when changing from kneeling to standing ($p < .0001$). While there was little lateral bending and twisting motion in either posture, standing reduced the twisting and lateral bending motion by approximately 2° ($p < .001$). The ratings of perceived exertion showed a trend across intervention conditions favoring standing as opposed to kneeling ($p = .054$). There were no differences in the spine motions for the FFP in the stretcher-side role.

3.2. Analysis of interventions

The MANOVAs conducted on the groups of dependent measures, specifically the EMG data, the motion data, and the moment data, showed significant intervention effects ($p < .001$). Figs. 2–5 show the results of the individual ANOVAs along with the differences detected using the multiple comparisons procedure. In all of the exertions studied, the posterior muscles showed a much greater response than the anterior muscles, and where there were significant differences between activations of the anterior

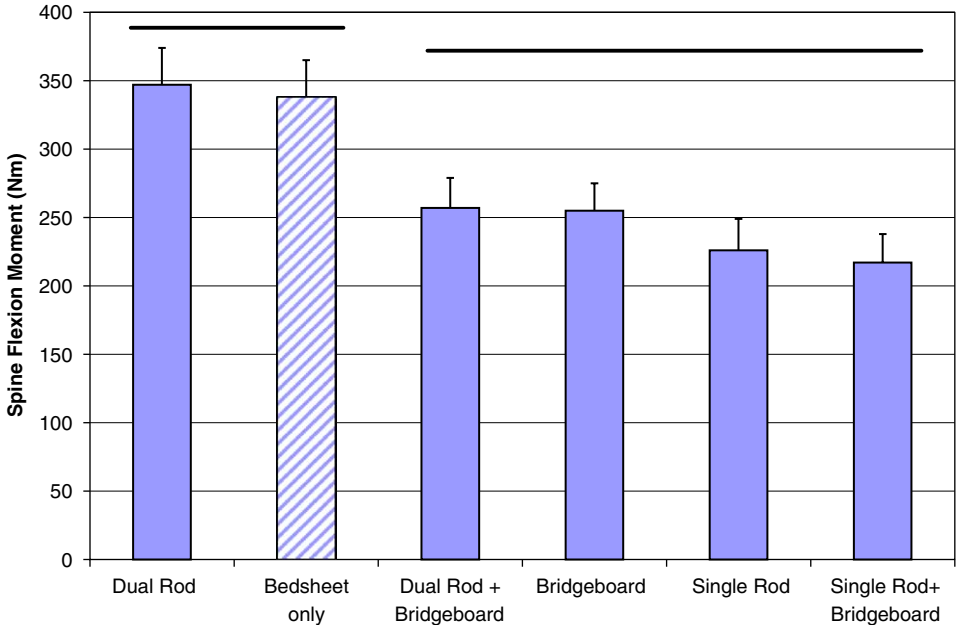

Fig. 2. The peak trunk flexion moments (Nm) averaged across the stretcher-side FFPs for each of the intervention and control (bedsheet only) conditions. The error bars show the standard error of the mean for each condition. The horizontal lines across the top of each graph show the results from the REGWQ multiple comparisons procedure.

muscles across intervention conditions, the changes tended to be small in magnitude.

Fig. 2 shows that for the FFP in the stretcher-side role, the net external spine flexion moments were reduced relative to the bedsheet only condition using the bridgeboard and the single rod. Given that the dual rod results are very close to the bedsheet-only results, the effect due to the combination of the dual rods and the bridgeboard is most likely due entirely to the bridgeboard.

The EMG data for the *stretcher-side* FFP (Fig. 3) shows the trade-offs in muscle activations with the various interventions. As the task changed from a lifting task to a pulling or dragging task when using the single rod, there is a significant decrease in the Erector Spinae recruitment and increased Latissimus Dorsi recruitment. However, the differences between intervention conditions were not significant for the LATL. In the case of the LATR, the increase in activation with the single rod is moderated by the bridgeboard, thus making it statistically equivalent to the bedsheet only condition. The bridgeboard significantly reduced the Erector Spinae activity bilaterally relative to the bedsheet only condition. Overall the Latissimus Dorsi was unaffected by the bridgeboard. Clearly, the dual rod intervention had little effect on muscle activation levels.

The EMG data for the *bedside* FFP (Fig. 4) indicates that the single rod led to a large and significant reduction in the Erector Spinae activation. It should be remembered that during these single rod conditions the FFP in the bedside role was no longer on the bed, but instead positioned along side the FFP in the stretcher-side role. Hence, the data look similar across the two roles, albeit slightly lower in magnitude for the FFP who was formerly on the bed and who now was responsible for transferring the lower half of the patient. For the bedside FFP, the bridgeboard only reduced the activation of the LATR. There was no significant change in Erector Spinae recruitment with the bridgeboard. The dual rod intervention failed to reduce muscle activation levels relative to the bedsheet only condition for all muscles sampled.

Spine postures were also affected by the interventions. The forward flexion of the stretcher-side FFP was greater when using the single rod, although this was lessened with the addition of the bridgeboard (Fig. 5). The flexion was essentially the same for all other intervention conditions. The amount of twisting also increased within the single rod conditions. Within either the kneeling or standing posture conditions for the FFP in the bedside role, there was little change in the degree of lateral bending, forward bending, or twisting due to the interventions tested ($p > .05$).

The Ratings of Perceived Exertion, while at the lower end of the scale, did show that the interventions differed when analyzed using a Wilcox rank test. Fig. 6 shows the summed rankings from the FFPs in each intervention and posture combination tested. Relative to the control condition, using only a bedsheet with the FFP on the bed in a kneeling posture, several interventions were perceived to require less effort for the FFP in the bedside role (Fig. 6a). These included the single rod condition, and any condition that incorporated the bridgeboard. For the FFP on the stretcher-side, all conditions that used the bridgeboard were perceived as less physically demanding.

4. Discussion

Results from this study show that incorporating ergonomic interventions into the FFP lateral transfer tasks

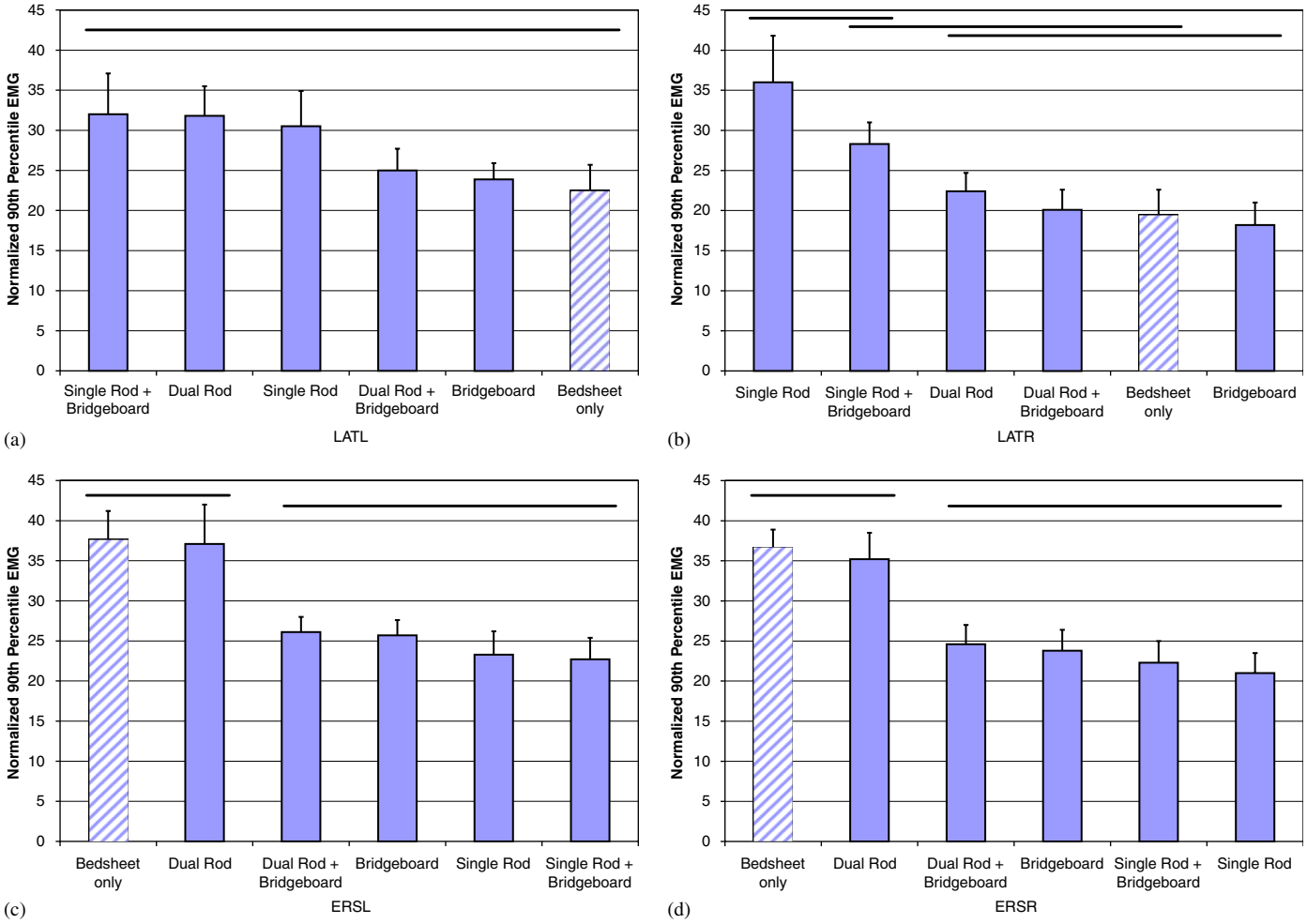

Fig. 3. The mean normalized 90th percentile EMG responses from the left and right Latissimus Dorsi muscles (graphs a and b) and the left and right Erector Spinae muscles (graphs c and d) of the FFP in the *stretcher-side* role. The error bars show the standard error of the mean for each condition. The horizontal lines across the top of each graph show the results from the REGWQ multiple comparisons procedure.

can reduce the biomechanical demands placed on the back. Both the objective and subjective data show that relative to the standard bedsheet transfer, both the bridgeboard and the single-rod interventions assisted one or both FFPs. However, when evaluating the array of dependent measures used, including the spine moments, the spine kinematics, the muscle activations detected with the surface EMG, and the ratings of perceived exertion, it is clear there are conflicting results.

4.1. Single rod

The single-rod intervention led to the lowest Erector Spinae recruitment while at the same time leading to the highest Latissimus Dorsi recruitment. For the FFP in the stretcher-side role, the single rod was associated with the largest amount of spinal flexion while at the same time the smallest spine flexion moment. This reduction of the spine flexion moment is indicative of a reduction in the total load on the spine. Increased flexion is typically associated with larger bending moments while lifting (Lavender et al., 2003). In this case, because the task was changed from lifting to pulling, the reduction in the external force applied more than compensated for the increased bending moment that would have been expected due to the increased trunk flexion. Interestingly, the increased Latissimus Dorsi activity was localized in the LATR muscles across both roles. This may be due to the subjects being predominantly right handed. It should also be noted that the LATR increase was moderated with the addition of the bridgeboard such that the post hoc tests failed to show the single rod + bridgeboard condition as being significantly different from the bedsheet-only condition in either role.

One concern verbalized by the FFPs during the initial focus groups in which the single rod concept was discussed was that the patient may roll away from the FFPs during the transfer. Should this occur, it could be an even more significant issue when laterally transferring patients from a stretcher to a hospital gurney. Our initial response to this was that the bedsheet could be used as a wrap so that the control could be maintained. In practice, however, this was

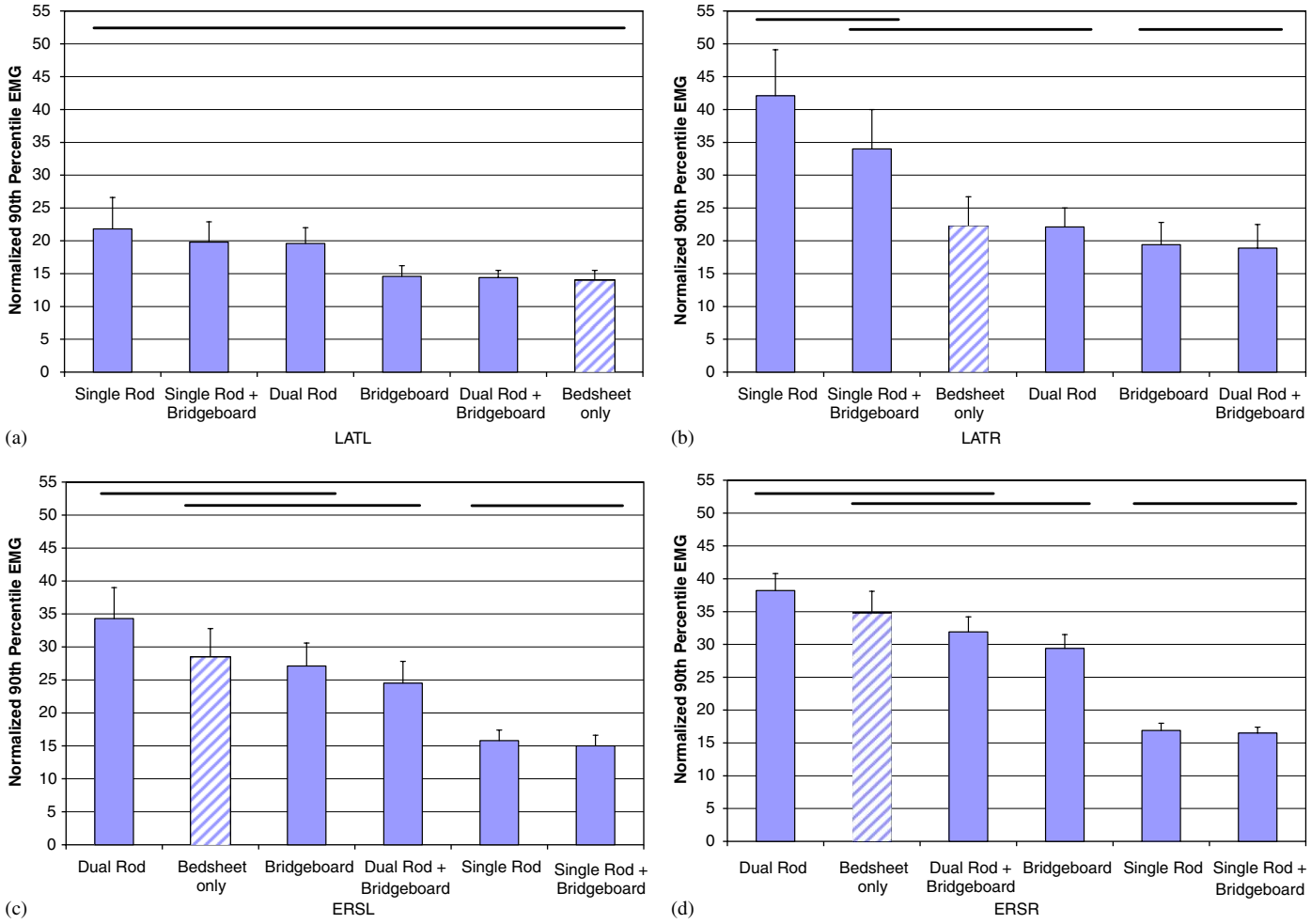

Fig. 4. The mean normalized 90th percentile EMG responses from the left and right Latissimus Dorsi muscles (graphs a and b) and the left and right Erector Spinae muscles (graphs c and d) of the FFP in the *bedside* role. The error bars show the standard error of the mean for each condition. The horizontal lines across the top of each graph show the results from the REGWQ multiple comparisons procedure.

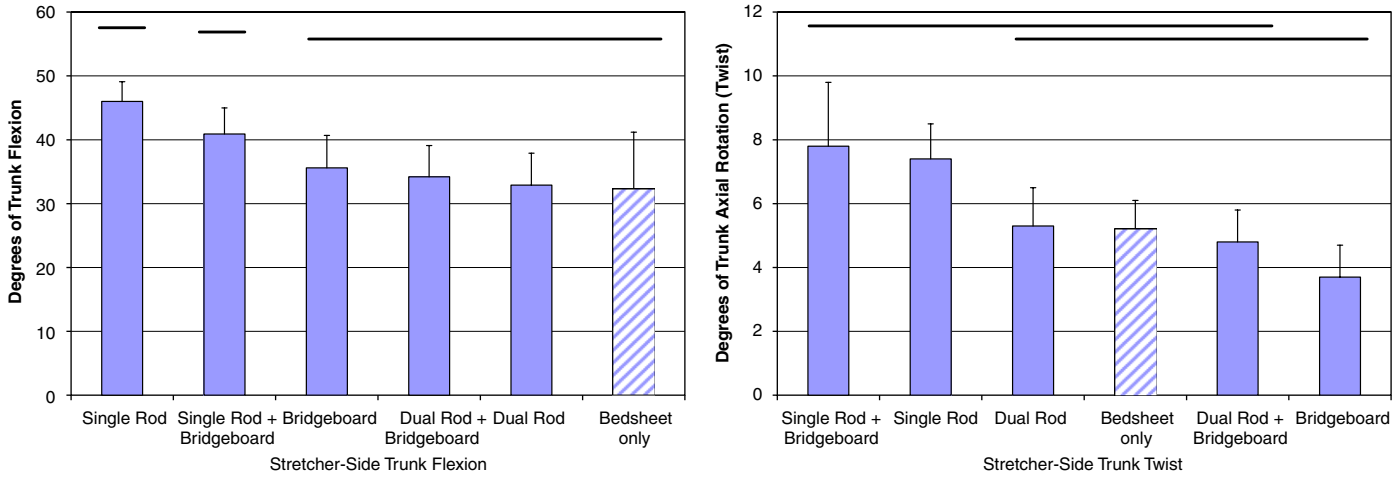

Fig. 5. The maximum torso flexion and axial rotation (twisting) averaged across the stretcher-side FFPs for each intervention condition. The horizontal lines across the top of each graph show the results from the REGWQ multiple comparisons procedure. The error bars show the standard error of the mean for each condition.

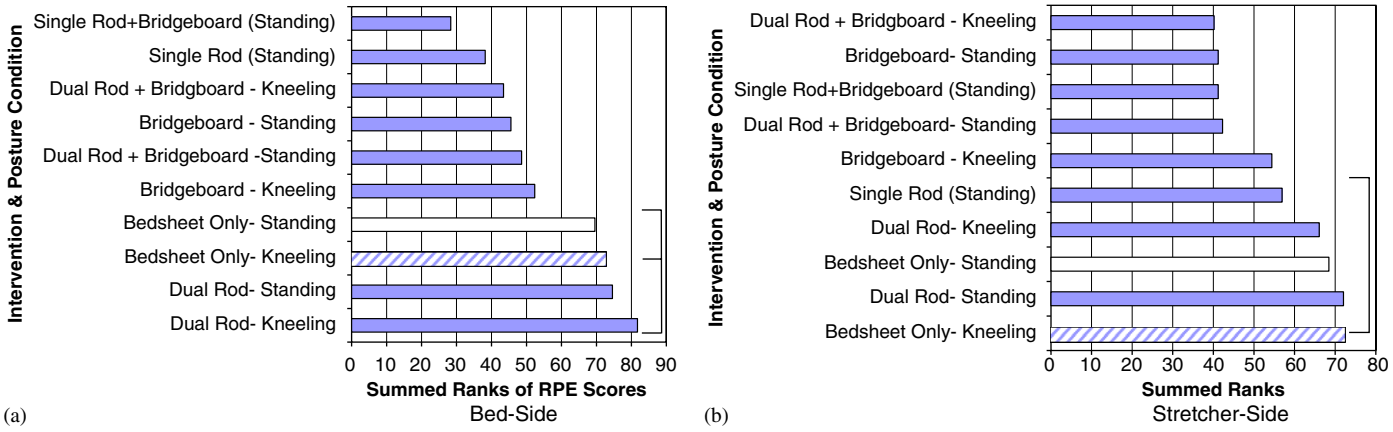

Fig. 6. The summed rankings of the RPE scores from the FFPs in the bedside role (a) and the stretcher-side role (b) for each of the tested intervention and bedside posture conditions. The bracketed conditions had equivalent rankings to the bedsheet only (control) condition.

never an issue. There was not one instance where the dummy rolled away from the FFPs during the testing. Moreover, the stretchers have rails on each side that prevent the patient from rolling. While these are normally collapsed while loading the stretcher, the distal rail could be left in the up position for stretcher to gurney transfers.

4.2. Bridgeboard

Use of the bridgeboard intervention during the two-sided lateral transfers reduced the net flexion moment, the Erector Spinae activity, and the ratings of perceived exertion values for the stretcher-side FFP. Interestingly, the bridgeboard did not significantly reduce Erector Spinae activity for the FFP in the bedside role. However, the activation levels of the Erector Spinae in the bedside role were lower overall when compared to the activation levels for the FFP in the stretcher-side role (32 vs. 37 percent MVC). In part this may be due to fundamental differences in the exertions performed in each of the two roles. The bedside FFP's role is to lift the patient. Given the challenges to postural stability faced by the individual in this role, little horizontal force can be exerted to aid in the transfer. Even though the bridgeboard reduces the friction encountered when sliding the patient, this two-sided method of transfer still requires the bedside FFP to lift when assisting in the transfer. In contrast, the FFP in the stretcher-side role lifts the patient and provides most of the horizontal force necessary to laterally shift the patient to the stretcher. The bridgeboard, by reducing the frictional forces opposing the lateral transfer, reduces the amount of lifting force that must actually be applied, thereby reducing the Erector Spinae recruitment.

The bridgeboard results are consistent with others who have looked into friction-reducing devices used for lateral patient transfer facilities in healthcare facilities (Hignett, 2003; Lloyd and Baptiste, 2006). There has been limited work evaluating the effectiveness of these devices with EMS workers (Massad et al., 2000). One of the ideas considered in our initial intervention identification and design process was the incorporation of a friction-reducing slip-sheet. Our initial pilot testing of this type of device revealed that the muscle recruitment would most likely be similar to those obtained with the bridgeboard during the actual transfer. However, use of the slip-sheet is predicated on the patient being fully on the sheet prior to transfer. This requires additional exertions as the patient is log-rolled once in each direction prior to the transfer taking place.

In terms of the qualitative feedback received from the FFPs, overall the FFPs responded favorably to the bridgeboard. It was pointed out that this would also be useful for the private ambulance companies who, according to our sample, frequently perform lateral bed to stretcher transfers. In addition, the FFPs confirmed that the device would be useful at the end of the run when the patient has to be laterally transferred from the stretcher to the hospital gurney. While many hospitals have slide boards for lateral transfers which, except for being slightly larger, are essentially the same as the slide board we used. However, these often are not available to ambulance crews.

4.3. Dual rod

The dual rod intervention did not work well. The only positive finding occurred when they were used in combination with the bridgeboard. Given that the bridgeboard by itself was accounting for most of this effect, use of the dual rods was not supported by the data. When asked about the dual rods after the experiment, the response to this intervention was mixed. While some FFPs pointed out the added control, many indicated that the square cross-section was uncomfortable on their hands. One hypothesis is that the added control of the bedsheet obtained through using the rods facilitated the transfer such that it occurred more quickly. Thus, the dynamic loads increased, perhaps offsetting the reductions that would have been expected due to the improved handling capacity. Alternatively, when

patients are moved with only the bedsheet, sometimes the lower extremities are not completely moved in the initial exertion. The FFPs would then perform a second smaller exertion in which they shift the legs and feet. This would serve to reduce the mass actually moved in the bedsheet only condition relative to the dual rod condition.

The testing protocol focused on the lateral transfer of a patient between the bed and the stretcher. It should be remembered that nearly every EMS run ends with the patient being laterally transferred from the stretcher to the hospital gurney. From the patient's point of view the transfers are similar in that they are lifted/slid from one horizontal surface to another. From the FFP's point of view there are notable differences between these two transfers due to the relative working heights involved. One of the limitations of our study was that we did not assess the interventions when performing the stretcher to gurney transfer. Nevertheless, we believe that the results from interventions tested would apply to this higher lateral transfer. Our previous work describing the posture (Lavender et al., 2000a) showed that the height of the hospital gurney reduced the trunk flexion. However, this means that the muscles of the arms and shoulders, in addition to those in the back, must be recruited, thereby making strength a concern (Lavender et al., 2000b). The friction reducing effects of the bridgeboard should reduce these strength demands. Likewise, the single rod should also be effective, although due to the more horizontal orientation of the applied force, the value of combining the single rod with the bridgeboard would likely be increased.

There are other limitations about this work that should be acknowledged. First, the training dummy used for the transfers weighed only 75 kg. This is just below the 50th percentile body weight value obtained from a sample of the working population in the US (Marras and Kim, 1993). Hence, in practice, a large proportion of the lateral transfers are performed on heavier individuals. We would like to believe that the benefits of using the single rod and the bridgeboard interventions would continue with heavier patients, but this remains to be tested. As we noted above, moving even the 75 kg dummy resulted in EMG activities greater than those recorded during our isometric MVC trials. This resulted in our replacing the MVC value with the measured EMG for the most demanding task, which also would have included an increased activity due to motion. However, the motions were typically slow and controlled, thus minimizing the contribution of the muscle dynamics to this maximal signal value. Moreover, given the within team experimental design, this adjustment to the scaling of the normalized EMG signal probably had little effect on the results and conclusions reached in this paper.

Perhaps one of the most significant limitations was that the results were based on a single trial from each team under each experimental condition. This was done due to the large number of heavy exertions required during each team's testing session and the requisite need to manage fatigue. One would anticipate that with increased experience the techniques used when working with the interventions would become more refined, further reducing the muscle recruitment required. Hence, we view the single trial as a conservative test of the interventions tested. One additional limitation was that we did not explore the effects of the size of the bed. This study used a double bed, based largely on the experiences reported by the suburban FFPs participating in our focus groups. We would expect similar effects with larger bed sizes (Queen or King size). It is possible that the positioning and posture of the bedside FFP might well be different if the patient were on a twin size bed. However, given that intervention effects were independent of the posture, it is likely that lateral transfers from smaller beds would produce results consistent with those reported above.

5. Conclusions

Relative to the conventional bedsheet transfer, the bridgeboard and single rod interventions were shown to be biomechanically advantageous. The bridgeboard's effect was focused on the FFP located on the stretcher-side of the transfer. The single rod significantly reduced the Erector Spinae recruitment for both FFPs. Combining the single rod with a bridgeboard reduced the increased Latissimus Dorsi activity found with the single rod by itself. FFPs in both roles rated the single rod conditions as the easiest exertions. While the FFPs in the bedside role tended to report lower perceived exertion ratings while standing, the objective data showed that it makes little difference in the muscle recruitment if the FFP who is on the bed stands or kneels. However, there is considerably more trunk flexion associated with the standing posture that could possibly increase the risk to the passive tissues supporting the spine.

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