A Comparison of Augmented Feedback and Didactic Approaches to Reduce Spine Motion During Box and Paramedic Lifting Tasks

by

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Abstract

Injury prevention movement (re)training (MR) for paramedics may be improved if they were guided by biomechanical and motor learning principles. The purpose was to compare MR approaches – didactic (DID) and augmented feedback (AUG) – in reducing spine motion during lifting tasks. Untrained participants (n=26) began with a lifting test (box, medication bag, and backboard), followed by their randomly-assigned intervention involving 50 practice lifts. The DID group began with a safe lifting presentation, whereas the AUG group was coached with augmented feedback. The lifting test was performed immediately and one-week after, while spine kinematics were quantified. After one week, AUG was strictly superior to DID in reducing spine motion in the retention task but was equivalent or superior for the transfer tasks. An AUG approach to MR is supported over didactic approaches to elicit lasting changes in practiced tasks, but more training is likely required to ensure transfer to unrehearsed tasks.
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# Table of Contents

Acknowledgments........................................................................................................................................ iii

Table of Contents........................................................................................................................................ iv

List of Tables ............................................................................................................................................... vii

List of Figures ........................................................................................................................................... viii

List of Appendices .................................................................................................................................... x

1 Introduction .............................................................................................................................................. 1
   1.1 Research Questions ......................................................................................................................... 5
      1.1.1 Research Question #1 ........................................................................................................... 5
      1.1.2 Research Question #2 ........................................................................................................... 5
   1.2 Hypotheses ............................................. 5
      1.2.1 Hypothesis #1 ....................................................................................................................... 5
      1.2.2 Hypothesis #2 ....................................................................................................................... 5

2 Literature Review .................................................................................................................................... 5
   2.1 Paramedic Occupation ................................................................................................................... 6
      2.1.1 Musculoskeletal Disorders amongst Paramedic Workers ....................................................... 6
      2.1.2 Biomechanical Demands of Paramedic Work ....................................................................... 8
   2.2 Biomechanics of Lifting ............................................................................................................... 11
      2.2.1 Physical Risk Factors for Low Back Disorders Associated with Lifting ............................. 11
      2.2.2 Lifting Low-lying Objects ..................................................................................................... 14
      2.2.3 Relationship between Lifting Frequency, Duty Cycle, and Spine Loading .................... 17
   2.3 Effectiveness of MSD Prevention Interventions for Emergency Responders .......................... 22
      2.3.1 Engineering Ergonomic Controls ......................................................................................... 22
      2.3.2 Movement (Re)training ......................................................................................................... 25
   2.4 Augmented Feedback to provide Guidance and Knowledge of Performance for the Learning of a Complex Motor Task ........................................................................................................... 28
      2.4.1 Using a Dowel for Position-Control Guidance to Facilitate Motor Learning .................. 30
      2.4.2 Terminal Knowledge of Performance Feedback ..................................................................... 35

3 Methods ............................................................................................................................................... 39
   3.1 Study Participants ......................................................................................................................... 39
      3.1.1 Recruitment and Inclusion/Exclusion Criteria ..................................................................... 39
3.1.2 Sample Size........................................................................................................39
3.1.3 Group Assignment ..........................................................................................40

3.2 Experimental Protocol .........................................................................................41
   3.2.1 Experimental Design ..................................................................................41
   3.2.2 General Procedure .....................................................................................42
   3.2.3 Box Lifting Task ........................................................................................46
   3.2.4 Medication Bag Lifting Task .......................................................................47
   3.2.5 Paramedic Backboard Lifting Task .............................................................49
   3.2.6 Augmented Feedback (AUG) Intervention .................................................50
   3.2.7 Didactic (DID) Intervention .......................................................................53

3.3 Data Collection and Processing .........................................................................55
   3.3.1 Data Collection and Instrumentation ..........................................................55
   3.3.2 Data Processing ..........................................................................................56

3.4 Statistical Analyses .............................................................................................59
   3.4.1 Summary of Dependent Variables ..............................................................59
   3.4.2 Statistical Tests ..........................................................................................59

4 Results ....................................................................................................................61
   4.1 Participant Characteristics ..............................................................................61
   4.2 Duty Cycles across all Tasks ..........................................................................61
      4.2.1 Duty Cycles in the Box Lifting Task .........................................................63
      4.2.2 Duty Cycles in the Medication Bag Lifting Task .....................................63
   4.3 Retention: Box lifting task .............................................................................63
      4.3.1 AUG Intervention Group ..........................................................................65
      4.3.2 DID Intervention Group .........................................................................65
      4.3.3 Between-group Comparisons ..................................................................66
   4.4 Transfer: Medication Bag Lifting Task ............................................................66
      4.4.1 Time Effects across both Intervention Groups .........................................66
   4.5 Transfer: Paramedic Backboard Lifting Task .................................................68
      4.5.1 Time Effects across both Intervention Groups for Peak Spine Flexion Angle.....70
      4.5.2 AUG Intervention Group .........................................................................70
      4.5.3 DID Intervention Group .........................................................................70
      4.5.4 Between-group Comparisons ..................................................................71
5 Discussion .......................................................................................................................... 72
  5.1 Retention: Box Lifting Task .......................................................................................... 72
  5.2 Transfer: Medication Bag and Paramedic Backboard Lifting Tasks ......................... 76
  5.3 Practical Application .................................................................................................... 80
  5.4 Limitations ................................................................................................................... 82
  5.5 Future Directions for Research .................................................................................... 84
  5.6 Conclusion ................................................................................................................... 85
6. References ........................................................................................................................ 87
Appendices ............................................................................................................................ 101
List of Tables

Table 1. Schedule of augmented feedback administration in the AUG intervention. KP: terminal knowledge of performance feedback. ..........................51

Table 2. Qualitative feedback provided by the research assistant and the corresponding peak spine flexion angle observed on the previous lift. ..........................53

Table 3. Participant characteristics at baseline. Values are presented as mean (SD). ..........................61
List of Figures

Figure 1. Schematic of the study design. Terms are represented by the following symbols. R: randomization; G: group; Did: didactic; Aug: augmented feedback; O: observation/test; box photo: box lifting task (retention test); bag photo: medication bag lifting task (transfer test); backboard photo: paramedic backboard lifting task (transfer test); I: intervention. ........................41

Figure 2. Diagram of marker setup. Sixteen total markers are used. Seven are used for calibration purposes only: one on the head (Head); two on bilateral acromioclavicular joints (RSH & LSH); two on bilateral iliac crests (RIC & LIC); and two on bilateral greater trochanters (RGT & LGT). Nine markers are used for tracking: four on the thorax (TRK1-4); and five on the pelvis (PEL1-5). ........................44

Figure 3. An individual performing the box lifting task. ........................................47

Figure 4. An individual performing the medication bag lifting task. ..............................48

Figure 5. An individual performing the paramedic backboard lifting task with a researcher. Participants always lifted the head-end of the backboard; the same researcher lifted the foot-end of the backboard with all participants. ........................49

Figure 6. During the first set of the AUG intervention, a blinded research assistant held the dowel to the participants’ back with two points of contact throughout the lifts: the mid-thoracic spine and the sacrum. Participants were instructed to attempt to maintain both points of contact with the dowel throughout the lifts to the best of their ability without allowing their low back to touch the dowel. ........................52

Figure 7. A participant listening to the DID intervention presentation given by a blinded research assistant. Participants were given the option to stand if they desired. .................................54

Figure 8. Results of the duty cycle analyses: A) Box lifting task; B) medication bag lifting task; C) paramedic backboard lifting task. The error bars indicate standard error of the mean (SEM). & significant difference between time-points across both groups. ..............................62

Figure 9. Results of the kinematic analyses for the box lifting retention task: A) Peak spine flexion angle; B) peak spine flexion velocity; C) peak spine extension velocity. The error bars indicate standard error of the mean (SEM). * significant difference between time-points in AUG group; # significant difference between time-points in DID group; † significant difference in immediate reduction between AUG and DID groups; ‡ significant difference ..........................65
in baseline-to-delayed retention test reduction between AUG and DID groups.

**Figure 10.** Results of the kinematic analyses for the bag lifting transfer task: A) Peak spine flexion angle; B) peak spine flexion velocity; C) peak spine extension velocity. The error bars indicate standard error of the mean (SEM). & significant difference between time-points across both groups.

Figure 11. Results of the kinematic analyses for the paramedic backboard lifting transfer task: A) Peak spine flexion angle; B) peak spine flexion velocity; C) peak spine extension velocity. The error bars indicate standard error of the mean (SEM). & significant difference between time-points across both groups; * significant difference between time-points in AUG group; # significant difference between time-points in DID group; † significant difference in immediate reduction between AUG and DID groups; ‡ significant difference in baseline-to-delayed transfer test reduction between AUG and DID groups.
# List of Appendices

**Appendix A.** Physical Activity Readiness Questionnaire (PAR-Q) .......................... 101  
**Appendix B.** Recruitment poster  ........................................................................... 102  
**Appendix C.** Information and Consent Form ............................................................. 103  
**Appendix D.** Borg’s CR-10 RPE scale (adapted from Borg, 1990) ......................... 106  
**Appendix E.** DID Intervention slideshow presentation .............................................. 107
1 Introduction

The risk for debilitating musculoskeletal injury amongst paramedics has been found to be up to seven times greater than the average working population, with injuries occurring primarily in the low back (Maguire, Hunting, Guidotti, & Smith, 2005; Reichard & Jackson, 2010). This, in part, is attributable to the commonly performed strenuous lifting of patients, stretchers, backboards, stair chairs, and medical equipment (Coffey, MacPhee, Socha, & Fischer, 2016). These patients/objects are lifted up and down staircases on calls regularly and can be heavy. For example, medical equipment average 24kg, stair chairs average 18kg, and motorized stretchers can be up to 80kg, all without considering the variable mass of the loaded patient (Coffey et al., 2016; Armstrong et al., 2017). Though the recent introduction of powered stretchers and loading systems can reduce peak low back loading exposures (Lad, Oomen, Callaghan, & Fischer, 2018), injury rates among paramedics remain considerable because the lifting of patients, backboards, stair chairs, and the heavy, motorized-stretchers (e.g., up steps and curbs) are still inherent requirements of the job (Armstrong et al., 2017).

Since engineering ergonomic controls (“fitting jobs to workers”) can be implemented in many occupations to reduce low back injury risk, and because there are mixed findings on the efficacy of administrative ergonomic controls (“fitting workers to jobs”), movement (re)training is generally not recommended (Hignett, 2003). However, emergency responders, such as paramedics or firefighters, represent workers who could benefit from such interventions given the unpredictable and non-modifiable nature of their work (Coffey et al., 2016; Makhoul et al., 2016; Beach, Frost, McGill & Callaghan, 2014; Prairie & Corbeil, 2014). For example, 82% of calls occur in unfamiliar indoor environments, meaning that the workplace demands cannot be adapted to the workers’ capacities (Prairie & Corbeil, 2014). Additionally, time pressure is a constraint exclusive to first-responders that can limit the available movement strategies used to perform the required tasks (Prairie & Corbeil, 2014; Lavender, Conrad, Reichelt, Meyer, & Johnson, 2000b). Thus, due to the unpredictable nature of the job, it is argued that movement (re)training interventions remains an important and viable approach amongst first-responders and needs to supplement ergonomic changes to the job (Fisher & WIntermeyer, 2012; Makhoul et al., 2016; Faber, Kingma, & van Dieën, 2007).

A challenge associated with the successful implementation of occupational movement (re)training interventions is ensuring the retention and transfer of learned movement patterns to
the workplace (Beach et al., 2014). Manual handling training often employs a didactic approach to teach theoretic concepts and promotes and utilization of “optimal” techniques applicable under a relatively narrow range of idealized situations (Garcia et al., 2011), which has limited effectiveness in attenuating injury risk (e.g., reducing rates of injury; Hignett, 2003; Morone et al., 2011; Garcia et al., 2011). Instead of aiming to teach “optimal” techniques with a didactic approach, movement (re)training may be more effective if a generalizable movement feature that is relevant to worker health and performance (e.g., limiting extreme spinal flexion when lifting) could be trained to be maintained. This may increase the likelihood that “safer” movement behaviors emerge and transfer across highly variable environments and lifting contexts, especially important considering the nature of paramedic work (Coffey et al., 2016; Makhoul et al., 2016). It has been shown in firefighters that an exercise intervention designed to elicit movement-oriented adaptations yields positive transfer of training to firefighter-specific tasks (Frost, Beach, Callaghan, & McGill, 2015a). As effective interventions have yet to be implemented for paramedics, it is important to identify movement (re)training approaches that can elicit spine-sparing lifting movement behaviors, programed in a way to maximize the potential for long-term learning. Effective training methods for use in paramedic movement (re)training interventions may be similar to those utilized in exercise and rehabilitation contexts, where training modalities that elicit long-term alterations in movement patterns have been used (e.g., Myer, Chu, Brent, & Hewett, 2008; Greska, Nelson Cortes, Van Lunen, & Oñate, 2012; Stevens et al., 2007).

One cost- and time-effective training modality that may be appropriate for paramedic movement (re)training is the use of a dowel as a tactile cue for lifting (re)training. The dowel is positioned along the posterior trunk with two points of contact (mid-thoracic spine and sacrum), and is used to train trainees to dissociate between hip and spine motion when lifting – popularly referred to as “hip-hinging” - because it can aid in limiting the straining of vulnerable spinal tissues such as intervertebral discs, posterior spinal ligaments, etc. (Liebenson, 2003; McGill, Andersen, & Horne, 2012; Montgomery, Boocock, & Hing, 2011; Adams, McNally, Chinn, & Dolan, 1994; Gunning, Callaghan, & McGill, 2001; Marras et al., 1995; Yang, Marras, & Best, 2011). Tactile cueing is a form of augmented feedback that has been found to facilitate motor learning via haptic position-control guidance (Sigrist, Rauter, Riener, & Wolf, 2013). This form of augmented feedback has been found to be especially beneficial in the early stages of learning a complex motor task, such as the hip-hinging pattern, by helping to acquire a first-movement representation and by giving the performer a reference of correctness to compare their inherent, proprioceptive feedback
to (Schmidt & Lee, 2005; Sigrist et al., 2013; Feygin, Kehner, & Tendick, 2002). Although popular in exercise contexts, there has been no known work published on the efficacy of the dowel used for lifting (re)training. Preliminary analyses from Carnegie, Chan, & Beach (2016) demonstrated that allowing individuals to practice with the dowel for two lifts prior to the performance of lifting tasks immediately reduced their peak sagittal lumbar spine flexion angle by 47%, flexion velocity by 43%, and extension velocity by 46% when compared to their self-selected technique. Such large improvements could attenuate low back injury risk associated with lifting if these acute responses can be retained and transferred to workplace practices.

Knowledge of performance (KP) is another important form of augmented feedback that is used to verbally inform the learner about their kinematics when executing voluntary, goal-directed movements (Schmidt & Lee, 2005). KP provided during deliberate practice has been found to be beneficial for long-term learning outcomes, such as transferability of a newly-learned task to a similar task with different demands and parameters (e.g., Weeks & Kordus, 1998). This is because when it is provided during practice, performers can use the feedback to modify their movements during subsequent task executions (Brisson & Alain, 1996a; 1999b), which has been found to decrease the time it takes for learning a motor skill by up to fifteen-fold (Scheidt et al., 2000). Currently, administration of KP and position-control guidance scheduled to elicit long-term adaptations have not yet been combined in movement (re)training interventions for the purpose of training workers to perform lifting tasks in a safer manner (i.e., with reduced spine motion). However, these methods show promise as they have been utilized successfully in the learning of complex sport skills (e.g., Weeks & Kordus, 1998; Zubiaur, Oña, & Delgado, 1999) and in rehabilitation settings (e.g., Marchal-Crespo & Reinkensmeyer, 2009).

The purpose of this study was to compare a movement (re)training intervention based on an augmented feedback approach (AUG) to one based on a standard didactic approach (DID) in their ability to elicit kinematic changes in the spine during the subsequent performance of the box lifts used in practice (i.e., retention), and medication bag and paramedic backboard lifts to assess transfer of training (i.e., the generalizability of learning; Weinstein, Pohl, & Lewthwaite, 1994; Schmidt & Young, 1987). It was hypothesized that because individuals in AUG intervention would acquire a kinesthetic understanding of what is recommended (i.e., limiting spine motion when lifting) and establish a reference of correctness (Feygin et al., 2002), they would exhibit greater reductions in peak sagittal spine flexion angle, spine flexion velocity, and spine extension velocity...
(established LBD risk factors; Adams et al., 1994; Gunning et al., 2001; Marras et al., 1995) compared to those in the DID intervention.
1.1 Research Questions

1.1.1 Research Question #1

Does a movement (re)training intervention utilizing an augmented feedback approach elicit larger reductions in sagittal-plane spine motion compared to a standard didactic approach during the performance of a box lifting task in the immediate and one-week delayed retention tests?

1.1.2 Research Question #2

Does a movement (re)training intervention utilizing an augmented feedback approach elicit larger reductions in sagittal-plane spine motion compared to a standard didactic approach during the performance of medication bag and paramedic backboard lifting tasks in the immediate and one-week delayed transfer tests?

1.2 Hypotheses

1.2.1 Hypothesis #1

A movement (re)training intervention utilizing an augmented feedback approach will elicit larger reductions in sagittal-plane spine motion compared to a standard didactic approach during the performance of a box lifting task in the immediate and one-week delayed retention tests.

1.2.2 Hypothesis #2

A movement (re)training intervention utilizing an augmented feedback approach will elicit larger reductions in sagittal-plane spine motion compared to a standard didactic approach during the performance of medication bag and paramedic backboard lifting tasks in the immediate and one-week delayed transfer tests.

2 Literature Review

The following review of literature was used to develop the research questions and hypotheses presented in sections 1.1 and 1.2.
2.1 Paramedic Occupation

2.1.1 Musculoskeletal Disorders amongst Paramedic Workers

Paramedic work involves regular performance of physically (and mentally) demanding tasks under a wide variety of unpredictable situations (presented in section 2.1.2). As a consequence, paramedics are at high risk for developing debilitating work-related musculoskeletal disorders (MSDs), currently defined by the Centers for Disease Control and Prevention as:

...injuries or disorders of the muscles, nerves, tendons, joints, cartilage, and spinal discs. Work-related musculoskeletal disorders (WMSDs) are conditions in which the work environment and performance of work contribute significantly to the condition; and/or the condition is made worse or persists longer due to work conditions (Centers for Disease Control and Prevention, 2016).

MSDs are detrimental to the well-being of the worker by reducing their quality of life, and have been found to contribute to the high rate of burnout leading to premature retirement amongst paramedics (Regehr & Millar, 2007). In addition, MSDs may jeopardize the quality of care offered by the ambulance service and create a financial burden on the healthcare system, due to the costs associated with worker compensations (e.g., Armstrong et al., 2017; Maguire et al., 2005; Aasa, Barnekow-Bergkvist, Ångquist, & Brulin, 2005).

Although the epidemiology literature is currently scarce (e.g., only two articles were included in a review of the MSD prevalence in paramedic workers by Broniecki, Esterman, May, & Grantham, 2010), it is generally accepted that paramedics are at risk for developing MSDs at some point during their careers. Discrepancies exist in the reported injury rates because each study is limited to the databases to which they have access, which is rarely more than several services. Additionally, injury rates may vary depending location of the service, because the physical demands and call frequency has been found to vary considerably between services in high-populous versus low-populous areas (Coffey et al., 2016). For example, Maguire et al. (2005) examined two urban ambulance services in the US and calculated an injury rate of 34.6/100 full-time equivalent (FTE) paramedic workers, which was greater than any other industry in the US and approximately seven times greater than the injury rate for the average individual in the year 2000. In two medium-sized paramedic services in Canada, similar injury rates of 34.2 and 42.0/100 FTE workers were found in 2010 (Armstrong et al., 2017). In a study performed by Reichard & Jackson (2010), a much lower injury rate of 4.9/100 FTE workers was found in 2000-2001. This
difference was likely attributable to the authors using the National Electronic Injury Surveillance System (NEISS-Work) which incorporated data from across the country (including high- and low-populous services) on both career and volunteer workers, and only included data on fully-reported injuries treated in the hospital emergency department. As the authors recognize this likely led to an underestimation of the injury rate, they extrapolated this injury rate to 14.5/100 FTE workers based on the finding that emergency department-treated injuries account for approximately one-third of occupational MSDs (CDC, 1998). A study from the UK with a relatively small sample size found that ambulance workers have a greater injury rate than the average working population with 15.1 versus 13.8/100 FTE workers, respectively (Johnson et al., 2005). Furthermore, according to Workplace Safety and Insurance Board (WSIB) statistics presented at a recent Centre of Research Expertise for the Prevention of Musculoskeletal Disorders (CRE-MSD) meeting (Wells, 2015), paramedics are between five and six times more likely to submit lost-time claims than any other rate group in Ontario. Thus, the literature consistently shows that the incidence rate for paramedic workers is greater than that of the average population, and often greater than that of other industries.

Of the MSD injuries reported, “sprains and strains” are the most common type of injury amongst paramedics. This was found in all the epidemiology studies reviewed, including work from Maguire et al. (2005), Reichard & Jackson (2010), Okada, Ishii, Nakata, & Nakayama (2005), and Aasa et al. (2005). Furthermore, these sprains and strains are consistently found to occur most commonly in the low back region (e.g., Sterud, Ekeberg, & Hem, 2006). In a large Japanese study involving 1551 paramedic workers, Okada et al. (2005) found that 66.6% of individuals self-reported a complaint of pain in the low back region in the past twelve months, with 42.6% of them indicating that this pain interfered with their work. Crill & Hostler (2005) reported that 48% of the convenience-sampled paramedic workers in the US reported experiencing back pain in the past six months, and 39% of the total sample believed their back pain was related to ambulance work. A large Swedish study with 1187 paramedic workers conducted by Aasa et al. (2005) found that amongst the 953 males and 234 females, 60 and 46% of these workers experienced at least one episode of low back pain (LBP) in the previous twelve months, respectively. This pain led to 11% of male and 14% of female paramedics to take time away from work, thus significantly increasing worker compensation costs. These findings were further supported by Maguire et al. (2005), where injuries to the back resulted in a lost workday rate of 6.2/100 FTE per year, which is three times greater than the lost workday rate resulting from the
second most commonly injured body part (the knees). Reichard & Jackson (2010) reported that 49% of all sprains and strains reported in paramedic workers occurred in the lower back, and 81% of which resulted from excessive physical effort or repetition of a bodily motion (excluding impacts). Thus, there is reason to believe that the high incidence MSDs amongst paramedics, specifically low back injuries, are associated with the physical tasks that they are required to perform while on the job. In the following section (2.1.2), what is currently known about the biomechanical demands of paramedic work will be examined in order to understand what types of tasks pose a high risk for injury to the low back.

2.1.2 Biomechanical Demands of Paramedic Work

During a typical twelve-hour shift, paramedics engage in sedentary work for approximately half of the time, interspersed with periods of high-intensity physical activity during which lifting, pushing, pulling, carrying, and running are required (Broniecki et al., 2010; Coffey et al., 2016; Prairie & Corbeil, 2014). Calls are unpredictable and can vary markedly in nature due to the unfamiliar environments, with 82% percent occurring in indoor locations and the majority occurring during the night (Prairie & Corbeil, 2014). Calls have been reported to range from rescuing victims from a plane crash, to individuals seeking help for a chipped finger nail (Tangherlini, 1998). Furthermore, paramedics servicing high-populous areas (defined as having a population greater than 196,966) have been found to have greater physical demands compared to their counterparts in low-populous areas (Coffey et al., 2016). Specifically, they have to load and unload stretchers without patients twice as often, carry medication bags four times as often, and respond to more calls (Coffey et al., 2016). Thus, although a description of an “average paramedic call” is elusive, understanding the demands of the frequently performed physical tasks may provide insight into which tasks contribute to increase the risk for injury.

Researchers have identified commonly-performed physically-demanding tasks by using interviews or surveys that inquire about tasks that are perceived to be difficult (Conrad, Lavender, Reichelt, & Meyer, 1997), qualitative physical demands descriptions (PDD) conducted by an infield observer (Coffey et al., 2016), or dynamic postural assessments to monitor individuals’ movement throughout a shift (Prairie & Corbeil, 2014). Lifting and carrying backboards (also known as a spinal board) and stair chairs up-and-down flights of stairs has been reported to be a commonly-performed task (Conrad et al., 1997; Coffey et al., 2016; Lavender, Conrad, Reichelt, Meyer, & Johnson, 2000b) and is required when a stretcher cannot be brought to the location of
the patient (Coffey et al., 2016). Patients are also frequently transferred from a bed to the stretcher and from the stretcher to a hospital gurney using a bedsheets method (Lavender et al., 2000b; Coffey et al., 2016; Prairie & Corbeil, 2014). Carrying medical equipment (i.e., the cardiac monitor, airway bag, and medication bag) is required for every call in Canada, and has an average total mass of 24kg (Coffey et al., 2016). Perhaps not surprisingly, 19.5% of paramedics across seven paramedic services reported this to be the most physically demanding task (Coffey et al., 2016). This was ranked second only behind the loading and handling of the stretcher (i.e., lifting the stretcher up and down stairs, loading it onto the ambulance, etc.), with 25% of respondents stating that this was the most physically demanding aspect (Coffey et al., 2016). Various studies have identified these aforementioned tasks as being the most physically demanding, and thus biomechanical analyses have been performed on these tasks in controlled settings (e.g., Cooper & Ghassemieh, 2007; Lavender, Conrad, Reichelt, Meyer, & Johnson, 2000b).

The emulation of paramedic-specific tasks in a laboratory setting allows for the measurement of the kinematics (i.e., position of body segments in time and space) and kinetics (e.g., measured force data used with kinematic data to quantify musculoskeletal loading) involved in those tasks. To determine which may be “risky”, these values can be compared to established threshold limit values, such as those set forth by NIOSH (Waters et al., 1994), or used in a logistic regression model (e.g., Marras et al., 1993) that assesses various parameters of the task to determine the probability that the task has a high risk for developing LBD (e.g., Lavender et al., 2000a; 2000b). Because injuries to the low back are the most prevalent in paramedics, the focus of this section will be on the demands imposed on the lumbar spine during the performance of the common paramedic tasks.

In a controlled laboratory setting using an average-weight mannequin of 467N, Lavender et al. (2000a; 2000b) found that lifting the backboard up from the ground and carrying it down the stairs to be a high-risk task, attributable to the initial lift. It requires the paramedics to lift off the ground (20-50mm starting height), and during this phase of the task, it was calculated that peak lumbar spine compression forces reached 5224N for the head-side lifter and 3955N for the leg-side lifter; both exceeding the NIOSH action limit (AL) of 3400N, indicating that performing these tasks increase risk for some workers (NIOSH, 1981). Lavender et al. (2000a; 2000b) found that stair chair lifts are nominal risk for low back injury, although compression values still approached the NIOSH AL. Horizontal patient transfers from bed-to-stretcher and stretcher-to-gurney resulted in spine compression values up to 7600N, which exceed the NIOSH maximum permissible limit.
(MPL) of 6377N and constitute increased risk for most workers (NIOSH, 1981). For stretcher (non-motorized, weighing approximately 368N) lifts down the stairs, both the initial lift and the descent for both paramedics had spine compression values exceeding the NIOSH AL, with average peak compression of 4500N on the initial lift and 3700N on the descent (Lavender et al., 2000a; 2000b). The spinal loads imposed by loading different stretcher systems into an ambulance compartment has also been studied by Cooper & Ghassemieh (2007), who found that psychophysically derived lifting limits (Snook & Ciriello, 1991) are exceeded with spine compression values reaching 3900N when using an Easi-loader system. In this system, the stretcher is lifted from one end, the front wheels are folded up by another paramedic, and it is pushed onto the ambulance. When using a ramp system, the authors found that the force needed to accelerate and decelerate the stretcher exceeded the safe limits set out by the British Standards for Machinery Operation (BS EN 1005-3, 2002), and for a motorized “tail-lift” system, the shear and compression forces are within the safe limits at all times but is the most time-consuming of the available methods. A recent in-field study by Prairie & Corbeil (2014) found that average peak lumbar spine flexion angle, an established low back disorder risk factor (e.g., Marras et al., 1995; see section 2.2.1), was 62.6° and observed when individuals were performing lifting tasks in general. To further support these findings, Coffey et al. (2016) had trained paramedics perform PDDs and found that in nearly every call, paramedics were required to lift a load greater than the NIOSH recommended weight limit.

It is important to note that many of the aforementioned studies utilize 3DSSPP (Center for Ergonomics, Michigan, USA), a biomechanical modeling software package that assumes negligible body segment accelerations during the lifts, thus neglecting the mass-inertial effects on musculoskeletal loading (Cooper & Ghassemieh, 2007). This assumption can be questioned in emergency response situations, however, as it has since been shown that paramedics lift and move faster during urgent calls – which represent nearly half of all calls (Prairie & Corbeil, 2014). Furthermore, patient masses can be much larger than the dummies used in the studies, such as a patient reported to be over 270kg (Tangherlini, 1998). Thus, because the literature is likely underestimating the loads that paramedics are experiencing on a daily basis (Lavender et al., 2000b), it is plausible that this excessive loading leads to the mechanically-induced tissue damage to the lumbar spine, contributing to the high incidences of low back disorders. Knowledge of the spinal loads could aid in the design and evaluation of ergonomic controls to attenuate low back injury risk. However, literature on the biomechanics of paramedic-specific tasks are scarce, and
there is currently very little epidemiological literature linking mechanical factors to low back injury within the paramedic context. Thus, in order to gain an understanding of why these paramedic-specific lifts may increase injury risk and how this risk can be attenuated, the following section will use these characterizations of paramedic tasks and situate them in the extensive lifting literature conducted within the manual materials handing context.

2.2  Biomechanics of Lifting

2.2.1 Physical Risk Factors for Low Back Disorders Associated with Lifting

The scientific literature suggests that low back pain (LBP) is caused by a complex interaction between an extremely wide variety of factors, meaning that the risk for developing LBP is multidimensional. Risk factors that have been linked to the reporting of LBP have been classified as psychosocial, organizational, individual (i.e., personal, such as strength capacity, age, and sex), and physical (Marras, 2008; McGill, 2007). Low back disorders (LBD) differ from LBP in that they may or may not manifest in symptoms of pain, and involve damage to tissues such as discs, ligaments or bone, via degeneration, rheumatic disorders, sprains, strains, or fractures (Park, 2013). Epidemiology research in the paramedic context has identified that these workers are at a greater risk for developing LBD than the average working population (e.g., Maguire et al., 2005; see section 2.1.1). This may not be surprising when acknowledging the macro-level physical LBD risk factors to which these workers are exposed. For example, seated vibration exposure from working as a driver has been linked to a greater risk of developing LBD (e.g., Magnusson, Pope, Wilder, & Areskoug, 1996; Pope & Hansson, 1992). Paramedics also frequently bend and twist when extracting victims from awkward spaces and working in the ambulance compartment (Prairie & Corbeil, 2014), and these movements have been linked with the LBD reporting in occupational settings (Marras et al., 1995; Punnett et al., 1991). Additionally, working in an occupation that requires heavy lifting has consistently been cited as a risk factor with strong evidence (e.g., Andersson, 1981; Bernard & Putz-Anderson, 1997). As the purpose of this thesis was to compare an augmented feedback to a didactic approach in their abilities to influence spinal mechanics during lifting, physical LBD risk factors related to lifting (i.e., those that haptic feedback and knowledge of performance were hypothesized to influence; see section 2.4) and associated mechanisms are discussed in this section.
A landmark paper published by Marras et al. (1995) identified biomechanical risk factors for LBDs. This was done by analyzing trunk motion characteristics of workers in 402 industrial jobs from 48 American manufacturing companies, and comparing the motions from jobs that were ranked as being low, medium, or high risk for LBD based on previously documented injury reports. Using an electrogoniometer that measures lumbar spine motion called the lumbar motion monitor (LMM), they were able to quantify 3D lumbar spine kinematics from the workers during the performance of MMH tasks. It was found that average spine velocity was one of the most important risk factors for LBDs, as a greater average spine velocity in any of the three cardinal planes was found to be a strong predictor of LBD risk when comparing the low- versus medium- and high-risk groups. The same could be said about maximum velocity and maximum acceleration, although the calculated odds ratios were smaller. Other risk factors that were identified by Marras et al. (1995) included the maximum flexion position, maximum twisting position, and the average and maximum low back moment. A multiple logistic regression model developed from the results of this study included five spine motion factors that distinguished between the high and low risk groups with an odds ratio of 10.7: lifting frequency, load moment, spine lateral velocity, spine twisting velocity, and the sagittal spine flexion angle (Marras et al., 1993). Further analysis on this dataset by Fathallah, Marras, and Parnianpour (1998) uncovered that individuals who performed complex, simultaneous high-velocity movement patterns involving the spine were exclusive to the high- and medium-risk groups, and were more likely to be in the high-risk group if extreme sagittal spine flexion was involved. How these motions act to increase LBD risk can be understood when the relationship between these kinematic and kinetic variables is examined.

Extreme lumbar spine flexion has been consistently cited as a poor posture to adopt, especially when lifting for various mechanistic reasons. For one, prolapsed intervertebral disc (PID) has been studied in vitro by Adams & Hutton (1982), where the authors aimed to determine if flexion was a prerequisite for PID. X-rays were used to determine the limits of normal lumbar flexion, and two vertebrae with the disc and intervening soft tissues were flexed to the determined limit. In this position, the joint was compressed with 8000N (to represent an average-weight male performing physically demanding lifts). If there was no failure of the joint, flexion was increased by 1° and compressed again; a process that was repeated until each specimen failed. Some specimens showed an anterior fracture in the vertebral body at smaller flexion angles, whereas 26 of the 61 specimens tested showed a PID at larger flexion angles, suggesting that hyperflexion of the spine is required for this injury to occur. Hyperflexion then, is more likely to occur in vivo.
when there is sufficient laxity in the posterior ligaments of the spine. This increase in laxity occurs through creep, and prolonged exposure to full flexion of the lumbar spine has been found to elicit this response (McGill & Brown, 1992). This occurs because the posterior passive tissues take over moment production when in full flexion, as it has been found that the trunk extensor muscles “turn off” in this position (i.e., there is a silencing in the electrical activity measured by EMG), termed the flexion-relaxation phenomenon (McGill & Kippers, 1994). However, full flexion of the spine is not necessarily required for injury to occur, as repeated spine flexion and extension movements with modest compression has been found to lead to disc herniation in vitro, with as little as 260N of compression leading to injury (disc herniation occurred more frequently with 867N and 1472N of compression; Callaghan & McGill, 2001). Thus, the combined effects of a flexed lumbar spine with loading may lead to injurious consequences, especially since a flexed spine may be up to 40% weaker when compared to a spine in a neutral posture (Gunning et al., 2001).

Spine compression is an important mechanism for injury: in the aforementioned flexed postures, in other deviated postures (i.e., laterally flexed and/or axially twisted), but also in a neutral lordotic posture. Brinckmann, Biggemann, & Hilweg (1988) have demonstrated in vitro that under axial compression only, the endplate is likely to be the first structure damaged. This group later determined that axial compression of as little as 2000-3000N is enough for micro-fractures to be observed in the endplate (Brinckmann, Biggemann, & Hilweg, 1989). High peak and average spine flexion velocities is an established LBD risk factor, and it follows mechanically because a large moment is required to produce acceleration of the trunk to move at high velocities, meaning a disproportionally large internal force (due to the mechanical disadvantage faced by trunk musculature) must be produced to generate this moment (Marras, 2008). These large internal forces can have axial components of compressive loading, but also anterior-posterior (A-P) and medio-lateral (M-L) shear (Marras, 2008). Large magnitudes of A-P shear (i.e., greater than 1000N) is a known mechanism of sustaining spondylolytic fractures, where the body of the vertebra slips forward relative to the vertebra above often due to the fracture of the pars interarticularis, thus separating the articulation between the spinous and inferior articular processes (Cyron, Hutton, & Troup, 1976; Lamy, Bazergui, Kraus, & Farfan, 1975). More recently, it has also been found that exposure to large magnitudes of A-P shearing when the discs are not degenerated is associated with stellate endplate fractures (Gallagher, Marras, Litsky, & Burr, 2006). M-L shearing and torsion are also a risk factors, as they have been found to be a mechanism for ligamentous rupture, especially if the two are combined with flexion (Roaf, 1960; Magerl et
Thus, not only does the posture of the lumbar spine influence the loading on the spine, but also influences the tolerance of the spine to the dimension of loading.

Although the internal forces can be summed and represented with a single vector, quantifying the peak and cumulative loading in the different dimensions is important because the vertebral column has different tolerance associated with different dimensions of loading (Marras, 2008). As a result, biomechanical research often quantifies the compression, A-P and M-L shearing, and torsion forces (if relevant) on the spine during the performance of the task of interest to gain insight on the relative risk of that task by comparing it to established guidelines and tolerance limits, such as those set out by the National Institute for Occupational Safety and Health (NIOSH; Waters, Putz-Anderson, & Garg, 1994). Spine kinematics are also often quantified without force measurements (i.e., dynamic postural assessments) when kinetic measurements are not feasible (e.g., in the field) or the risk associated with the task can be established by identifying kinematic LBD risk factors present in the movements (e.g., Lavender et al., 2000b; Prairie & Corbeil, 2014). These methods allow for the identification of work tasks that need to be improved via ergonomic controls.

2.2.2 Lifting Low-lying Objects

Paramedics are often required to lift low-lying objects or patients off the ground. For example, one task that is commonly performed and found to elicit the highest peak lumbar spine compression and flexion angles across all common paramedic tasks is the backboard lift off the ground (20-50mm above floor level), with peak compression values exceeding the NIOSH AL for both paramedics (Lavender et al., 2000a; 2000b). Lifting low-lying objects (i.e., objects at or close to ground level) has been known to be a risky task because untrained individuals have been found to be generally unable to perform the task whilst maintaining a lordotic posture of the lumbar spine (Noone & Maxumdar, 1992; Straker, 1999). This section will explore research that has been conducted on the demands of lifting objects from a low initial height, and what techniques or strategies have been suggested to attenuate the risk associated with the task.

A study conducted by Nielsen et al., (1998) described the muscular load of the low back during lifting with different starting heights. Low back muscular load was defined as the percentage of EMG-measured muscle activation of the bilateral erector spinae muscles, with 100% being the maximum voluntary contraction (MVC) measured at baseline (peak force was measured simultaneously). The participants used self-selected lifting techniques to lift 10kg mail transport
boxes and place them on a desk 80cm above the floor starting from low heights of 36.3 and 54.4cm, medium heights ranging from 72.5 to 126.8cm, and high heights of 144.9 and 163.0cm. The authors found a main effect of initial lifting height on muscular loading, with the largest mean muscular loads occurring when starting from low lifting heights (no difference between medium and high heights). Nielsen et al. (1998) estimated the L5/S1 disc compression by assuming a linear relationship between the extension force produced and the muscle activation, and by incorporating anthropometric data from Dempster (1955) and Potvin (1997). The authors found that low initial lifting heights resulted in the largest peak compressive forces at the L5/S1 disc of 2400N when compared to the other height conditions. Another study from Lavender et al. (2003) examining the effects of initial lifting height, load magnitude, and speed on peak L5/S1 moments during lifting yielded results that were in-line with the findings of Nielsen et al. (1998). Participants were asked to use a self-selected technique to lift from the floor, knee height, and knuckle height, to a table at elbow height (heights were relative to each participants’ upright standing). The study involved three factors: mass (4 levels), initial vertical location (3 levels), and speed (normal and fast). It was found that there was a significant main effect of initial lifting height, with the peak L5/S1 moment from the floor height significantly greater than from knee height, which was significantly greater than from knuckle height. Lifting height alone accounted for 43% of the variance in the peak moment, greater than half of the total variance explained when also considering the load magnitude and lifting speed ($r^2 = 0.72$). Hoozemans, Kingma, de Vries, van Dieën (2008) followed from this work and aimed to quantify the compression and A-P shear forces in addition to the net moments at the level of the L5/S1 disc for lifts starting at different heights. Participants stood in front of a bookcase and were asked to lift a box with handles using a self-selected technique from one of the four shelves to their waist-level at upright standing. The initial heights of the box handles were 0.32, 0.73, 1.14, and 1.55m, and had masses of 7.5kg and 15kg. By combining a dynamic 3D linked segment model (LSM) with an EMG-driven anatomical trunk model (Kingma et al., 1996), regression analysis showed that per 10cm increase in initial starting height of the box, the peak low back moment, L5/S1 compression force, and L5/S1 A-P shear decreased by 7.0Nm, 146.9N, and 15.7N respectively, when the load was constant. Thus, the consensus in literature is that the lower the initial height of the load being lifted, the greater the muscular load, peak spine flexion angle, peak low back moments, and peak compressive and A-P forces. As these findings have been predicated on individuals using self-selected techniques, efforts have been directed at determining if there are lifting strategies that are safer to use for these low-lying lifts.
A review of evidence by Straker (2003) compares the use of the squat, semi-squat, and stoop lift techniques for lifting low-lying objects. A squat lift is characterized by large knee and hip flexion and a trunk that is near-vertical; a stoop lift by nearly-extended knees and a trunk that is near-horizontal; and a semi-squat technique incorporates aspects of both the squat and the stoop, with a moderate amount of knee flexion and trunk inclination (Straker, 2003; Burgess-Limerick, 2003). His summary suggests that the use of a stoop technique results in slightly smaller lumbar moments and compression forces than the squat or semi-squat techniques (within a 5% range), while the squat technique reduces A-P shearing compared to the stoop. The squat technique may require more lower extremity strength, the stoop may require more trunk extensor strength, and the semi-squat may be a compromise if the individual has strength limitations (e.g., Li & Zhang, 2009; Straker & Duncan, 2000). As there are tradeoffs when selecting one technique over another, it is not conclusive which is definitively better. Kingma, Faber & van Dieën (2010) explored the use of the free (i.e., self-selected), squat, stoop, and weight-lifters’ technique (WLT) to lift a box that is too wide to fit between the knees at two low initial heights. For the WLT, participants were verbally instructed to spread their legs so the outer edge of the feet were apart for a distance equal to 60% of their height, bend the knees until their patellae were over their toes, and to flex the hips while maintaining a lordotic lumbar spine curvature. They lifted a 15kg, 0.57m wide box (comparable to lifting a patient on a backboard, as this is just wider than the shoulder width of the 95th percentile male; Haslegrave, 1986) from two different initial heights to hip-level at upright standing. For each technique, they lifted the box by the handles and the bottom, which were 34 and 7cm above the floor, respectively (both initial heights have been considered “low” in previous work; see Nielsen et al., 1998). Using the same aforementioned musculoskeletal modeling approach (Kingma et al., 1996), it was found that the WLT was generally superior to the other three conditions when the box was lifted at the handle height. The WLT elicited a smaller peak L5/S1 extension moment and lumbar flexion angle than the stoop and free lifts, and ≥ 20% reduction in peak L5/S1 compression force compared to the free, stoop, and squat lifts. When lifted from the bottom of the box, the use of the WLT showed a smaller peak lumbar spine flexion angle and average distance between the L5/S1 and the box than the other conditions. However, it did not yield any differences in peak L5/S1 compression, while eliciting a greater peak A-P shear force compared to the squat and stoop techniques. Although spine loading was not improved, it is known that the tolerance to compression and shearing is posture dependent and may be more tolerant when the lordotic curvature in the lumbar spine is maintained (Adams et al., 1994; Gunning et al.,
Thus, it may be beneficial to identify methods of reducing spine motion when an “optimal” technique for low-lying lifts cannot be identified (Kingma et al., 2010; Makhoul et al., 2017).

In a recent study conducted by Makhoul et al. (2017), they did not attempt to identify an “optimal” pre-lift posture that may minimize the magnitude of risk factors (use of spine-sparing techniques), but instead utilized a work-energy approach to find a determinant of such risk factors that could occur at any point during a lift. This dynamic assessment may be better to characterize lifting technique, as the static posture adopted pre-lift does not necessarily determine what may occur during the movement. The authors examined the correlation between a measure of work done by the lower body relative to sum of lower body work and spine work, called relative lower body work, and three different risk factors for LBD: absolute and body mass-normalized peak sagittal L4/L5 moment and peak sagittal spine angle during the performance of paramedics-specific lifting tasks. One of these lifting tasks was the commonly-performed backboard lift off the ground in which two paramedics performed the task as similarly as they could to an actual emergency situation. For this low-lying lift, Makhoul et al. (2017) found that the relative lower body work measure was not correlated to the L4/L5 moments, but did show a significant inverse-correlation with the peak sagittal spine angle ($r_s = -0.818, p < 0.001$). Thus, instead of focusing on what pre-lift static posture to adopt prior to the lifting of low-lying loads, it may be beneficial to train paramedics to generate more work from the lower-extremities to reduce the magnitude of lumbar spine deviation, thus maintain tolerance to the large compressive loads (Adams et al., 1994; Gunning et al., 2001) associated with lifting from low initial heights (e.g., Lavender et al., 2000b). Section 2.3.2 will explore what movement (re)training efforts have been used for paramedics thus far, and a teaching modality will be proposed in section 2.4 to help elicit these important movement changes when paramedics are faced with lifting tasks.

2.2.3 Relationship between Lifting Frequency, Duty Cycle, and Spine Loading

Paramedics work in situations where the speed of which they perform their duties may mean the difference between life or death (Tangherlini, 1998), especially in urgent calls, defined in literature as situations where the immediate transport of the patient(s) is required due to a threat to life or limb (Prairie & Corbeil, 2014). Dynamic postural assessments conducted during paramedic shifts showed that during urgent calls, both trunk motion and the frequency of performing lifting tasks increases during medical care and patient-handling activities, to the point
where the risk for LBD is elevated (Prairie & Corbeil, 2014). In this section, the literature regarding lifting frequency, duty cycle, and spine loading was reviewed in order to gain an understanding of how these variables relate to one another with the aim to identify areas where movement (re)training can intervene.

Much of the work in this area has been focused on the effects of increasing lifting frequency on spine loading, which has been typically measured in terms of lifts per minute (lpm) enforced by metronome-pacing. This has been used to analyze individuals’ responses over short period of time (e.g., eight minutes used by Nielsen et al., 1998), or over a duration that may be representative of a workday for a manual material handler to understand the role fatigue might play (e.g., Marras et al., 2006). These frequencies were not selected to directly force the individuals to perform the lifts in less time (i.e., reduce their duty cycle, defined as the duration of effort directed towards lifting; Potvin, 2012), as even the largest frequencies used in experiments still allowed enough time for participants to use their preferred duty cycle (e.g., Hagen, Sørhagen, & Harms-Ringdahl, 1995; Nielsen et al., 1998). However, researchers have found that just by increasing lifting frequency without constraining duty cycle, individuals tended to perform lifts faster (i.e., reduce their duty cycle; Nielsen et al., 1998), potentially (in part) due to the perception of a time constraint, considered to be a psychosocial stressor that can influence lifting behaviour (Marras et al., 2000). Research has also aimed to study the effects of lifting speed directly, and this has been done by using verbal commands (e.g., “lift faster”). This, unfortunately, means that lifting speed cannot be controlled relatively nor absolutely due to methodological difficulties, but is typically quantified. Literature using the lifting frequency paradigm will be reviewed, followed by research on lifting speed/duty cycle elicited by verbal commands.

A previously-reviewed study (section 2.2.2) conducted by Nielsen et al. (1998) examined the muscular load on the low back during lifting from different heights and frequencies. For 8-minute trials, participants lifted 10kg mail transport boxes from three different initial heights to an 80cm-tall desk, at three different lifting frequencies: 6, 12, and 18 lpm (corresponding 10, 5, and 3.3 seconds/lift cycle times, respectively). Nielsen et al. (1998) found a main effect of frequency on the EMG activity (i.e., muscular load) of the erector spinae, with muscular loads increasing as frequency increased. Interestingly, as frequency increased, the duration of the EMG bursts decreased, indicating that participants decreased their duty cycle when they did not have to. The greatest mean muscular load and estimated L5/S1 compression occurred at 18 lpm frequency (for each initial lifting height), which was interpreted as being driven by the voluntarily-selected
increased lifting speed (decrease in duty cycle). Increasing lifting frequency itself, however, does not appear to increase loading. For example, another study conducted by Marras et al. (2006) found that lifting frequency alone had an effect on spine lateral shear, but only the 8 lpm condition differing, with no effect found on compression and A-P shear. They had novice and experienced manual material handlers undergo 8-hour shifts of lifting (divided into four two-hour sessions) with one of three possible loads, 1.1, 4.9, or 11.7kg, assigned to each individual. All six frequency conditions of 2, 4, 6, 8, 10, and 12 lpm, enforced by when the load was presented to them, were to be completed by the participants on separate days, in random order. The loads were lifted from an initial height of 88cm, 74cm away from the individual to a destination height of 121cm and asymmetry of 90°. Using an EMG-assisted biomechanical model, the results showed a complex interaction between lift frequency, duration of exposure (i.e., hours into the day), and work experience. Although the authors incorrectly hypothesized that lift frequency would dominate spinal loading patterns, the experience of the lifters played an important role. Novices had higher loading at the high frequencies of 8, 10, and 12 lpm, while experienced subjects had higher loading at the low frequencies of 2, 4, and 6 lpm, suggesting that individuals had developed a preferred movement strategy for the lift rates to which they are most-commonly exposed (Marras et al., 2006). Thus, whether or not individuals chose to lift faster as frequency increased, spine loading does not necessarily increase with lifting frequency. Another study using the lifting frequency paradigm was conducted by Hagen et al. (1995), where experienced workers lifted a box starting on the ground (handles were 21cm above the ground) to upright standing with “hanging” arms (i.e., knuckle height). Each participant performed these various conditions with different mass (kg)/frequency (lpm) combinations until a steady VO\textsubscript{2} was reached: 1/20, 8.5/10, 8.5/20, 17/10 and 17/20. Participants were given brief instruction of technique, and performed all conditions with both the squat and stoop techniques on two separate days. The authors found that there was no main effect of frequency on the motion ranges during stoop lifting, but there was an effect on thigh motion during squat lifting, where individuals went through less thigh motion range as the frequencies increased. Although the increase in trunk motion during squat lifting at higher frequencies was insignificant, the authors suggested a true difference may exist, but was not captured because the individuals lifted faster and the low sampling frequency used (10Hz) likely underestimated the segment acceleration and peak velocity. Although not conclusive, the results of lifting frequency literature seem to show that individuals do not necessarily increase loading with increased lifting frequencies, but (either consciously or subconsciously) decrease duty cycles.
even when not required to—they may or may not lift faster depending on their experience at lifting with the specific frequency. A decrease in duty cycle (i.e., increase in lifting speed) can result in an increase muscular loading and peak spine velocities if individuals use the same spine range-of-motion when performing the lifts. Research on increased lifting speed (i.e., decreased duty cycles) elicited with verbal commands will be evaluated to understand the direct effects of lifting speed on loading.

Lavender, Li, Andersson, & Natarajan (1999) evaluated the peak L5/S1 spine moments in three different lifting tasks with two different lifting speeds and box masses. The box was lifted from the floor (handles were 27 cm above the floor) to elbow level in the first task; the second task required them to lift from the same starting location and place it on top of the 61 cm-tall pedestal on their right; and the last task required them to lift the box from the pedestal from their left, and place it on the pedestal to their right. They performed each task with the box masses of 10% and 20% of their body mass, and two qualitatively-defined speeds of slow (completed in approximately 3-4 s), and fast (participants were asked to lift "as fast as possible"). Using 3D model with seven rigid body segments, they found that in the symmetrical task, lifting speed was associated with a 16% increase in peak sagittal bending moment and a slight (significant) increase in peak twisting moment at the L5/S1 when compared to the slow condition. For the second task, faster lifting was associated with a greater peak sagittal bending and twisting moment; and for the third task, faster lifting was only associated with greater peak sagittal bending moments at the spine (greater twisting moments were observed at the knees and hips). Lavender et al. (1999) concluded that the effects of lifting as fast as possible increases moments in the sagittal plane regardless of the weight being lifted across any of the three tasks. In fact, compared to previously published work on lifting speed in sagittally symmetric lifts by Bush-Joseph, Schipplein, Andersson, & Andriacchi (1988), De Looze et al. (1994), Dolan, Earley, & Adams (1994), and Gagnon & Gagnon (1992), their calculation of a 16% increase in sagittal bending moment during the fast sagittally-symmetric lifts was conservative, as others have consistently found a greater increase over the slow condition, such as Dolan et al. (1994) calculating an increase of 180% in sagittal bending moment. Lavender et al. (1999) explained that this was likely due to the fact that an EMG-assisted model was not used, thus overlooking any contributions of trunk musculature co-contraction on spinal loading. This group of researchers published another study four years later (Lavender et al., 2003; previously reviewed in section 2.2.2) examining the effects of initial lifting height, load magnitude, and lifting speed on peak L5/S1 moments in sagittally symmetric lifting, and observed similar
results to Lavender et al. (1999). A significant main effect of lifting speed existed and accounted 4% of the variance in the peak moment. The effects of lifting speed were more pronounced when lifting from lower heights, and when the loads are lighter. Perhaps most relevantly, lifting a heavy load (300N) from the floor at high speeds (the condition closest to resembling a paramedic backboard lift) resulted in a peak flexion moment of 40Nm (25% increase) greater than observed during the same lifts at a self-selected speed.

There are some general conclusions that can be drawn from this extensive body of literature (that this review cannot fully cover). For one, when lifting frequency is increased and individuals do not reduce their duty cycle, there appears to be no detrimental effects on spinal loading; instead, individuals’ experience with a certain frequency is more important (Marras et al., 2006). Increasing lifting frequency without individuals reducing their duty cycle does not seem realistic, however, as they tend to lift faster (perhaps subconsciously to maintain their rest time; Nielsen et al., 1998; Hagen et al., 1995). When they do, the consensus in the literature is that spinal loading increases, specifically the peak L5/S1 dynamic moment, regardless if the lift is sagittally symmetric or not (e.g., Lavender et al., 1999). It is important to note, however, that increasing lifting speed may increase loading on average, but it does not have the same effect on each individual’s movement behavior. A recent study conducted by Frost, Beach, Callaghan, & McGill (2015b) questioned the use of low-demand (i.e., low velocity and load) tasks to make inferences about the movement strategies employed to execute high-demand tasks. One of the tasks that they analyzed kinematically was lifting a box from the ground. When the participants were asked to lift fast, they showed an average response of increased hip and decreased knee angle, suggesting a more “hip-dominant” pattern used. However, further insight into the individual responses to fast lifting showed that at least one of the 52 participants showed a significant change in both more and less motion for every dependent measure – indicating that the direction of adaptation (mentioned above) was not representative of individual participants. Thus, it is possible that increasing lifting speed does not necessarily lead to an increase in spinal loading in all individuals, and instead, it may depend on characteristics of individual performers. The implications of this is that the increased spinal loading associated with increased lifting speed may be attenuated if key kinematic features that help to reduce spinal loading (i.e., neutral spine) could be taught to be maintain during lifting, regardless of the task and demand. Although this has been the goal of some movement (re)training interventions (e.g., Beach et al., 2014), many still aim to teach a “correct” lifting technique to use for all tasks. Where movement (re)training interventions look to improve workers’
movement behaviours during physical tasks, ergonomic engineering controls aim to fit the job to the worker by eliminating the need to perform the risky task altogether. The following section will review the efforts aimed towards reducing MSDs amongst paramedics, and the effectiveness of these efforts.

2.3 Effectiveness of MSD Prevention Interventions for Emergency Responders

2.3.1 Engineering Ergonomic Controls

Physical ergonomics is concerned with the (re)design of the workplace, equipment, and work systems to accommodate the capabilities of human workers with the intention of reducing the risk for injury related to the performance of repetitive or forceful tasks (Rodts & McLaughlin, 2017). Ergonomic design may also help reduce worker compensation costs associated with injuries, reduce absenteeism, and improve work productivity (Rodts & McLaughlin, 2017). As such, ergonomic interventions have been found to be effective in controlled workplace environments where the environment and tasks are controllable. For example, the systems approach-led ergonomic redesign of the IBM manufacturing factory in 1983 led to higher employee satisfaction rates, improved quality of production, and a reduction in injury rates, which led to annual cost savings of $500,000 (Helander & Burri, 1995). There are many other success stories where engineering ergonomic controls have significantly reduced the risk for injury associated with commonly performed tasks in a job, by redesigning work. Although the majority of paramedic work occurs in highly variable environments (e.g., 82% of calls occur in unfamiliar indoor environments; Prairie & Corbeil, 2014) there are tasks that are consistently performed with the same equipment (i.e., the raising and lowering of stretchers), which enable engineering ergonomic interventions. This section looks at the effectiveness of recent engineering ergonomic controls implemented in the paramedic occupation.

One ergonomic intervention that has been implemented in the Toronto Paramedic Service is the low-friction bridgeboard that aids with horizontal patient transfers from bed to stretcher, and from the stretcher to hospital gurney (Lavender et al., 2000a; 2000b; 2007). It was experimentally determined that the horizontal patient transfer without the bridgeboard (using a bedsheet method) results in spine compression values up to 7600N, which exceed the NIOSH maximum permissible limit (MPL) of 6377N and constitute increased risk for most workers (Lavender et al., 2000a;
Thus, the bridgeboard was designed to facilitate sliding the patient (as opposed to lifting) between two surfaces by reducing the friction between the bedsheet and the surface below. Although the effects on injury rates have not been reported, it has been found that the net spine flexion (external demand) moment, erector spinae activity, and ratings of perceived exertion are reduced compared to using the traditional bedsheet method (Lavender et al., 2007). Thus, when trained to make use of the bridgeboard properly, individuals may reduce the spinal loading associated with the task and therefore reduce the risk for low back injury.

Perhaps the most important recent contribution to paramedic work from ergonomic design is the introduction of motorized load systems and stretchers. Motorized load systems are used to lift a stretcher up into the ambulance compartment without requiring a worker to do so. One such loading system is called the “tail-lift” system, where the stretcher is pushed onto the tail-lift by the worker, raised using a motor, and then pushed into the ambulance (Cooper & Ghassemieh, 2007). Biomechanical analysis showed that when using this new load system, neither ambulance workers experienced compression or shearing loads greater than BSEN limits (BS EN 1005-3, 2002), whereas loading the stretcher using the traditional folding-leg method (described in section 2.1.2) was found to exceed both the BSEN and Snook recommended safe limits for compression (Snook & Ciriello, 1991; Cooper & Ghassemieh, 2007). Motorized stretchers, such as the Stryker® Power-PRO™ XT (Portage, MI) used by the Niagara Emergency Medical Service, raise and lower the undercarriage automatically, thus requires little effort from the workers after initially placing the patient on the stretcher. A field study conducted by Lad, Oomen, Callaghan, & Fischer (2018) found that the combined tasks of loading the patient onto the powered stretcher, raising it, and using a load system reduced spine compression by 62% compared to the use of a manual stretcher to perform the same task. The use of these motorized load systems and stretchers appear to reduce the exposure to biomechanical MSD risk factors, and similar positive effects on the incidences of injury is observed in epidemiology studies.

To determine if there was an effect of implementing powered stretchers on paramedic injury rates, Studnek, Crawford, & Fernandez (2012) analyzed injury reports submitted to the Austin Travis County EMS Record Management System and the Worker Compensation administrator’s database by the ambulance services of Austin city and Travis County from 1999 to 2008. Prior to the implementation of the Stryker® electronically powered stretchers from 1999-2006, the calculated injury incidence rate was 61.09/100 FTE workers, with injury rates of 12.65 and 6.56/100 FTE workers for back injuries and stretcher-related injuries, respectively. Following
the implementation of the stretchers in late 2006, the overall injury rate from 2007-2008 declined to 28.76/100 FTE workers, with back and stretcher-related injury rates declining to 5.10 and 1.98/100 FTE workers, respectively. An injury rate ratio was calculated as the ratio of incidence of injury in the post-intervention group to pre-intervention group as an estimated measure of intervention effect. Stretcher-related injuries showed the largest rate reduction post-intervention followed by back injuries, suggesting the powered stretchers directly and immediately elicited a reduction on the incidences of paramedic MSDs. A similar study was conducted in Canada by Armstrong et al. (2017), where they examined the effectiveness of the implementation of powered stretchers as well as load systems in a medium-sized paramedic service. The Niagara Emergency Medical Service (NEMS) had powered stretchers and load systems implemented in early 2014 and was compared to the Hamilton Paramedic Service (HPS), considered the control service of a similar size. Injury data was obtained from January 2010 to December 2015 for both services. In the NEMS, the overall MSD injury rate and the stretcher-related injury rate decreased by 43% and 73%, respectively, from pre- to post-implementation of the Stryker® Power-PRO™ XT and Power-LOAD™ systems (Portage, MI); neither the overall injury rate or stretcher-related injury rate decreased in the control service. Not only does the implementation of these motorized stretchers and load systems appear to have an immediate effect on reducing injury rates in various services, but they are also cost effective. This was determined by Armstrong et al. (2017) because the reduced costs associated with worker compensations pays back for the additional costs of the motorized stretchers and load systems after 5.8 years, with the system life estimated to be seven years. In response to this research proving the injury- and financial-reduction effectiveness of these ergonomic controls, many ambulance services are now implementing this technology. Ergonomic interventions involving equipment provision aimed at reducing the effort and loading associated with patient handling tasks are typically effective in reducing injury risk in other healthcare professions (e.g., Hignett, 2003), and this was found to be true in the case of motorized stretchers and loading systems for paramedics.

Just as it has been shown in other industries, engineering ergonomic controls are effective in reducing the risk for injury associated with the handling of stretchers amongst paramedics. However, as previously mentioned, first-responder occupations (i.e., paramedics and firefighters) are difficult to control and design as the work environments are highly variable (e.g., Coffey et al., 2016; Prairie & Corbeil, 2014). As such, engineering ergonomic controls are still scarce in the paramedic occupation, with many of the most physically-demanding and “risky” tasks, such as the
backboard lift, patient transfer and carrying of medical equipment, remaining mostly unchanged (e.g., Lavender et al., 2000b; Coffey et al., 2016). Furthermore, there remains to be a substantial injury rate (30.3/100 FTE workers in 2014) and stretcher-related injury rate (9.9/100 FTE workers in 2014) after the implementation of powered stretchers and load systems. This may be because of various reasons, including the fact that the lifting of a heavy stretcher (25kg heavier than the non-motorized stretchers) is required when transporting patients up and down porches, curbs, stairs, etc. (Armstrong et al., 2017). Furthermore, research has shown that in the face of new ergonomic interventions, workers may actually change their lifting behaviour in ways such that the reduction in low back loading due to the intervention is attenuated (Faber, Kingma, & van Dieën, 2007). Thus, instead of solely focusing on fitting the job to the worker, efforts must also be directed towards preparing the worker for the job. Movement (re)training interventions aimed at improving worker movement mechanics to reduce exposure to biomechanical MSD risk factors remains an important approach to supplement ergonomic improvements as part of a comprehensive strategy for injury prevention (Makhoul et al., 2016).

2.3.2 Movement (Re)training

Movement (re)training interventions aimed to reduce LBP have been offered for industry workers for a long time, with the first “back-school” offered in Sweden back in 1969 (Forssell, 1981). The aim of the Swedish back school was not to treat LBP, but instead attempted to prevent episodes of LBP by changing how workers move and load their spines in their daily living tasks. In-class lessons were given on anatomy, spine biomechanics, epidemiology of LBP, pathophysiology of LBDs, posture, ergonomics, and treatment methods (Garcia et al., 2011). However, the practical aspect was underrepresented, consisting of only a brief practice of exercises for part of one of the four days (Garcia et al., 2011). Movement (re)training programs today typically utilize a similar didactic approach, where emphasis is on education and psychosocial risk factors for LBP, and less attention is on practice and exercise (e.g., Lønn et al., 1999; Cecchi et al., 2010). Literature tends to show inconclusive evidence on the effectiveness of such programs (e.g., Hignett, 2003; Martimo et al., 2008), and experts who study LBDs suggest that this is attributable to the use of a “blanket approach” that is very unlikely to benefit the majority of those participating in the programs because the information and practice is not specific to workers’ demands and relevant injury mechanisms (e.g., McGill, 2007). Additionally, it has not been demonstrated that providing information on spinal anatomy and physiology is effective in eliciting
changes in movement behavior and/or lifting techniques. However, after acknowledging the shortcomings of a pure ergonomic approach to preventing injuries for paramedics, it becomes clear that movement (re)training interventions are necessary, at least, to supplement the improvements that ergonomic interventions can bring (Makhoul et al., 2016). Unfortunately, no known movement (re)training programs for reducing the risk for MSDs specific to the paramedic occupation have been documented. One barrier has been the challenge to documenting paramedic work demands; for example, ergonomists are not typically afforded opportunities to perform in-field assessments due to the risk of being exposed to traumatic events and/or the potential of interfering with the paramedics’ work. It has recently been made possible to understand the specific demands through surveys, dynamic postural assessments using new technology (e.g., the CUELA system used by Prairie & Corbeil, 2014), and by training paramedics to perform PDDs on the job (Coffey et al., 2016; see section 2.1.2). In this section, movement (re)training interventions with a focus on practicing and performing tasks specific to their occupation will be examined.

In a large study testing the effects of different exercise programs on low back loading during the performance firefighter-specific tasks, Beach et al. (2014) recruited sixty male firefighters and separated them into three intervention groups. The MOV group progressed through a movement-oriented exercise program consisting of exercises that address common movement deficiencies observed in athletes and patients (i.e., not specific to firefighting). The coach emphasized movement quality and provided feedback on visually-observed uncontrolled movements with the aim of stabilizing the key kinematic features that are known to reduce injury potential, whilst eliciting maximal physical fitness improvements. The FIT group went through a different program also aimed to elicit maximal improvements in physical fitness, but the coaches’ cues were primarily focused on motivation and general technique flaws. The CON (i.e., control group) participants maintained their normal exercise routine throughout the study duration. Before and after participation in their respective twelve-week programs, participants’ kinematics and kinetics were measured to calculate spinal loads during the performance of the same nine simulated occupational tasks: symmetrical and asymmetrical lifts, unilateral push and pull, ceiling breach and pull, forcible entry, overhead chop, and hose pull. In this short-term transfer test, both FIT and MOV participants improved in all measures of physical fitness used in this study, an area where the CON participants remained relatively stable. However, there was no clear indication from the kinetic analysis that either the MOV, FIT, CON elicited “spine-sparing” techniques (i.e., maintaining key features within movement that reduce risk) when performing the post-intervention
transfer tests, with the hose pull being the only task where the MOV and FIT group responded differently than CON. However, secondary kinematic analysis showed that the MOV group displayed less spine and frontal plane knee motion during the performance of the tasks, whereas as the FIT group showed the opposite effect (Frost et al., 2015a). Thus, although the exercise program with emphasis on movement quality did not reduce the spinal loading compared to other exercise programs, the reduction in frontal plane knee and spine motion means that the knee and the spine were loaded in positions with greater load-bearing tolerance (Chaudhari & Andriacchi, 2006; Gunning et al., 2001; Adams et al., 1994). Because firefighters have many work characteristics similar to that of paramedics (i.e., being first-responders working with variable situations and demands, and also having high-incidences of LBDs; Reichard & Jackson, 2010), programs with this type of focus (i.e., on how movements are performed) may be helpful for the paramedic population as well. More investigation is required to determine the long-term outcomes of such a program, and there are currently no programs of this sort for paramedics. The literature though, does not appear to support an isolated technique training approach to these LBP prevention programs.

A systematic review conducted by Hignett (2003) determined the number of high, moderate, and limited evidence level studies (scored with a critical appraisal tool developed by Downs & Black, 1998) supported or rejected the use of three types of interventions strategies to reduce MSD associated with handling patients in various healthcare occupations. Multifactor interventions typically included risk assessments, equipment provision, education and training, physical fitness training, and/or other components. These were found to be successful, but almost equally many studies included in this review also showed a null finding. Single factor interventions were typically successful if it was based on either the provision of equipment or the lifting team approach. Technique training-based interventions were not found to be successful by four studies with strong evidence, eight with moderate evidence, and five with limited level evidence. This approach was found to have both positive and negative outcomes by two moderate and four limited evidence studies, whereas it was found to be successful in the short-term by four moderate level studies, and four limited studies. A closer inspection unveiled that interventions in these studies (i.e., the ones pertaining to the effects of technique training-based interventions) often utilized either a didactic based approach to teaching technique with little practice or exercise involved, and no studies applying motor learning principles to the teaching of these skills. A similar result was found in another review by Martimo et al. (2008) looking at studies that investigated the
effectiveness of movement (re)training and equipment implementation for lifting in general (i.e., study participants ranged from baggage handlers, postal workers, to health care workers, and more). The interventions that aimed to train individuals to lift with specific techniques that reduce the risk for developing LBD were found to have no long-term effect. It is important to note that Martimo et al. (2008) identified that none of the feedback provided in the interventions reviewed was individualized, indicating that these interventions were blanket interventions. Thus, the advice given is unlikely to be appropriate to improve everyone’s technique.

The evidence currently does not support the effectiveness of movement (re)training interventions for patient handling activities, firefighters, and materials handlers. Although the current methods do not appear to work, it is important to recognize that current programs are typically structured around a didactic component (which may exist because it has been included since the first back school; Forssell, 1981), and no empirical evidence that supports that being taught about spinal anatomy or physiology, for example, aids in changing movement mechanics. Additionally, there is seldom individualized feedback provided, thus each individuals’ different movement “problems” are likely not attended to during these interventions. In fact, when individuals were given individualized feedback from a coach in the study by Beach et al. (2014), the firefighters showed significant improvements in spine motion and frontal plane knee motion (Frost, 2013). Furthermore, the use of augmented feedback following established principles from motor learning research is lacking in such programs, although they are effective in strength and conditioning and rehabilitation contexts to alter trunk, hip, and frontal plane knee control (e.g., Myer et al., 2008; Greska et al., 2012; Stevens et al., 2007). Thus, because movement (re)training remains worthy of consideration as an approach to prevent injuries amongst paramedics (e.g., Beach et al., 2014; Makhoul et al., 2017), effective programs must be created by improving on previous programs’ short-comings and using principles from motor learning research during deliberate practice, which should be the central component for programs with this intention.

2.4 Augmented Feedback to provide Guidance and Knowledge of Performance for the Learning of a Complex Motor Task

Motor learning refers to the acquisition of relatively permanent changes in the capability for producing an action, and results from practice or experience in performing the action (Schmidt & Lee, 2005). It is not directly observed as the relevant changes are internal, and thus must be inferred through observation of change in movement behavior (Schmidt & Lee, 2005). This can
be done by evaluating the kinematic features of interest during performance, typically in two different tests. One is the retention test, where the context is same as the tasks during practice, and the transfer test, which differs in context to practice, to indicate the generalizability of the learning (Winstein, et al., 1994; Schmidt & Young, 1987). Aside from practice, augmented feedback has consistently been cited as one of the most important factors to facilitate the motor learning (e.g., Thorndike, 1927; Bilodeau, 1966; Magill, 2001; Sigrist et al., 2013). Augmented feedback refers to supplemental information provided about the performance or outcome of the task, whereas inherent feedback is part of the information that is present during or resulting from the execution of the task (Schmidt & Lee, 2005). Some types of inherent feedback, such as being able to visually see whether or not the basketball went through the hoop, does not require evaluation. Many types do, however, such as the afferent proprioceptive information about spine posture during the performance of a lift (Schmidt & Lee, 2005). For these types of inherent feedback to be used to minimize error (in this case, unwanted movement features), individuals must learn to evaluate them by comparing them in an error-detection process to a learned “reference of correctness” (Schmidt & Lee, 2005). Many forms of augmented feedback may facilitate the establishment of a reference of correctness, such as haptic, visual, auditory, or multimodal feedback (Sigrist et al., 2013), and can be given at various times: concurrently (i.e., during the task, also known as online); or terminally (i.e., after the task, also known as offline; Schmidt & Lee, 2005). Much research in the motor learning literature has focused on how (i.e., what kinds, frequency, when relative to the task, etc.) to administer augmented feedback to increase the likelihood of successful learning of a specific skill or movement feature (e.g., Sigrist et al., 2013).

Brief movement (re)training interventions were implemented in this current study to determine if spine-sparing lifting technique (i.e., the maintenance of an approximately neutral spine posture during lifting; McGill, 2004) could be better elicited using an approach with augmented feedback compared to an approach with didactic teaching. In the augmented feedback (AUG) intervention, two forms of feedback were incorporated: haptic feedback using a dowel, and knowledge of performance (KP) provided via terminal verbal information regarding the peak flexion position obtained during the lift. The forms and administration of feedback in the AUG intervention was based on research supporting how to use these forms of feedback to increase the likelihood of transfer of learning to maintain the desired kinematic features during unrehearsed tasks. The design of the AUG intervention (outlined in section 3.2.6) was based on the following body of literature.
2.4.1 Using a Dowel for Position-Control Guidance to Facilitate Motor Learning

For the AUG intervention in this thesis project, participants were exposed to one set of lifting practice with a dowel positioned along the posterior trunk of the learner with two points of contact: mid-thoracic spine and sacrum. Told to maintain contact with both points during the lift whilst preventing any contact between their low backs and the dowel, the objective was to teach participants to dissociate between hip and spine motion when squatting and lifting, which is commonly referred to as “hip-hinging”. The dowel used in this manner is a teaching modality that has been widely used in exercise contexts (e.g., McGill et al., 2012; Liebenson, 2003; Montgomery et al., 2011). However, the effectiveness of the dowel to elicit short- and/or long-term changes in tasks with parameters and context similar and dissimilar to practice has not been researched. Preliminary analyses conducted by Carnegie et al. (2016) exposed participants to the dowel during two practice repetitions of sagittally-symmetric box lifts immediately prior to the performance of the same tasks without the dowel. Acutely, their peak lumbar spine flexion angle was reduced by 47%, flexion velocity by 43%, and extension velocity by 46% when compared to their self-selected technique. These dramatic responses may reduce LBD risk if they can be retained and transferred to tasks in the workplace. The potential mechanism(s) for why using the dowel in this manner may be an effective teaching modality and how to use it to maximize the probability of short- and long-term retention and transfer of spine-sparing lifting will be discussed in this section.

As mentioned previously (section 2.4), concurrent augmented feedback that provides a reference of correctness to the learner to compare with their inherent feedback may facilitate the retention and learning of a motor task (Schmidt & Lee, 2005). In this specific case, the dowel acts as a tactile cue to provide concurrent haptic augmented information indicating the adoption of an approximately neutral spine posture during lifting, and this information is used to establish a reference of correctness that individuals can use to evaluate their position as indicated by inherent afferent proprioceptive feedback in subsequent lifts without the dowel. Although visual cues are the most potent source of inherent information and dominate when available (e.g., Schmidt & Lee, 2005), proprioceptive feedback is the primary source of information available to the learner to inform them about their spinal posture during lifting because one cannot visually observe their spinal posture. Even though spinal posture may influence the individuals’ vantage point, there are other factors that can influence this (i.e., posture of the lower extremities, direction that the head faces, etc.); thus, vision cannot be relied on as the primary source of information. This method of
using concurrent haptic augmented feedback to provide the proprioceptive sensation of the required movement pattern is called guidance (Tsutsui & Imanaka, 2003), or specifically, position-control-based guidance (Schmidt & Lee, 2005; Sigrist et al., 2012), and has been shown to have a strong positive effect on performance during the acquisition phase and immediately after (e.g., Singer, 1980; Carnegie et al., 2016). It has also been used in rehabilitation settings for the purpose of movement (re)training, such as by Marchal-Crespo & Reinkensmeyer (2009) where a high number of repetitions using robotic devices to assist in movement retraining was found to be able to help re-establish normative movement patterns of walking, and multi-joint arm and hand movements. It is also thought to be beneficial because it prevents the occurrence of errors during practice (i.e., unwanted movement characteristics); however, this can be detrimental to learning if overused, as suggested by the guidance hypothesis (Schmidt, 1991; Salmoni, Schmidt, & Walter, 1984).

The guidance hypothesis postulates that the guiding properties of augmented feedback are beneficial for motor learning when it is used to reduce error during practice, but is detrimental when relied upon (Schmidt, 1991; Salmoni et al., 1984). Many studies were instrumental in the formation of this hypothesis, including an important study conducted by Armstrong (1970). He tested the use of terminal knowledge of performance (KP; see section 2.4.2), concurrent visual KP, and physical guidance during a task where individuals are to produce elbow movements to move a lever through a four-second spatial-temporal pattern that was their goal. The group with terminal KP received verbal indication of their kinematic performance after each trial and a visual plot of their traced trajectory compared to the goal trajectory after each block of trials. The group that had concurrent KP viewed a monitor providing a real-time visual plot of their movement trajectory with the goal trajectory for every trial. Lastly, the group with guidance was assisted with a mechanical device during the task that physically corrected movements that deviated from the goal path during every trial. During the acquisition phase (i.e., practice), those with guidance made very few errors at a constant rate throughout acquisition, whereas those with concurrent KP began with more errors and gradually reduced to a constant rate of errors that was greater than those in the guidance group. The group with terminal KP began with by far the most errors in their movement, and gradually decreased to a constant rate that remained greater than those in the concurrent KP group. However, in the transfer test without feedback, it was found that individuals who were given guidance for every practice trial performed with the most error, followed by the group with concurrent visual KP, with the least amount of errors in the terminal KP group. From this study, it
appeared that guidance given during all trials led to immediate performance improvements, but was not effective in eliciting transfer of learning. Other studies also found results that support these findings, such as one conducted by Singer & Pease (1976). In their manipulation apparatus involving the use of foot pedals and hand-manipulative objects, it was found again that those with guidance performed the best during the acquisition of the task, but was inferior to the discovery learning and combination learning groups on both the retention and transfer tests on the following day. Another study conducted by Winstein et al. (1994) had participants practice moving to a target using an angular positioning level on a table. Four different groups were involved: one group was provided with physical guidance at high frequency; one had faded frequency physical guidance (i.e., frequency decreases throughout practice); another had knowledge of result (KR) at high frequency; and the last group had KR with faded frequency. In-line with the guidance hypothesis, it was found that individuals with physical guidance at high frequency had the poorest retention both twenty minutes and one day after the acquisition phase, and high frequency for both forms of feedback was inferior compared to the same form of feedback with the faded feedback schedule. Thus, augmented haptic feedback for guidance is not beneficial for learning when it is provided throughout the entire practice (i.e., acquisition phase), likely because the individuals are prevented from making errors, which impedes the learning process because individuals are not exposed to opportunities to calibrate to the environment by comparing their inherent feedback to a learned reference of correctness (Schmidt, 1991; Schmidt & Lee, 2005). Accordingly, it has been found that errors are important to motor learning, as when errors are prevented from being made, the time required for successful motor learning may increase by up to fifteen times (Scheidt et al., 2000). This led other researchers to determine if benefits exist when guidance-based feedback is provided only some of the time (to still allow for errors), and if guidance is more beneficial to some types of tasks over others.

Although too much guidance appears to be detrimental to learning, coaches and rehabilitation clinicians still commonly use haptic position-control-based guidance to provide a first movement representation (i.e., a kinesthetic image; Féry & Morizot, 2000) of the closed motor skill to be performed (e.g., Marchal-Crespo et al., 2013). How can it be implemented successfully to facilitate motor learning without creating a dependence, and which skills should it be used for? Research has shown that some guidance is beneficial when it is provided with practice trials without guidance. For example, the previously mentioned study conducted by Winstein et al. (1994) involved a group who received physical guidance with faded frequency during practice,
and this group performed the best (i.e., with the least absolute constant error) of the four groups during the transfer test with a different context (to test the generalizability of the learning) one day after acquisition. Another study conducted by Sidaway et al. (2008) compared the use of manual guidance versus KR during the learning of a weight-bearing skill (important to individuals with neurological conditions that present with asymmetrical weight-bearing during stance) presented with two different frequencies: 33 and 100%. Although the group who received KR for 33% of the trials performed the task with the least absolute constant error in the one-week retention test, the group who received guidance for 33% of the trials performed the second best on this retention, significantly better than the groups with either KR or guidance provided 100% of the trials. Another study conducted by Hagman (1983) investigated the effects of exposure to different frequencies of physical guidance during the performance of a task that required individuals to reach a goal position on metal slide that moved left to right along a linear track. Each group had three blocks of practice consisting of six trials. One group was given a physical stopper to signal the goal position 50% of the trials, another had guidance on 83% of the trials (only the last trial of each block was performed without the stopper), and the last group had the stopper for 17% of the trials - on the first trial of each block only. The individuals who had guidance once at the beginning of the acquisition trials (17% group) performed significantly better than those who had it for 50% of the trials, who performed significantly better than those who had it for 83% of the trials on the retention test 24-hours post-acquisition. Thus, the consensus in literature is that retention and transfer of a motor task is improved with guidance if it is given only some of the time, with more towards the beginning of practice. Research has also found that position-control-based guidance to be more beneficial to learning when provided for the practice of complex tasks (such as a lifting with a neutral spine). For example, Wulf, Shea, & Whitacre (1998) examined the effects of guidance by using a pair of ski poles as a guidance tool for the practice of a ski-simulation task. It was found that those who had the poles for learning acquired a more efficient movement pattern than those who practiced without the guidance tool, as they performed better in the retention test than the group practicing without poles. A complex bimanual upper limb coordination task involving side-to-side movements was devised by Tsutsui & Imanaka (2003) to test the effects of having guidance for all practice trials, practice without guidance, and two intermediate conditions with varying proportions of guidance and practice-only trials. Guidance-only practice led to significant improvements in performance (i.e., reduction in root mean square error) in the retention tasks, but intermediate proportions of guidance and practice led to the greatest improvements on
the retention task. Another study conducted by Marchal-Crepo & Reinkensmeyer (2008) had participants perform steering tasks with a force-feedback steering wheel in a simulated visual environment from the point of view of sitting in a wheelchair. Their complex task was to steer the wheelchair following the black line as closely as possible. The no-guidance group performed the task 30 times without feedback; the fixed-guidance group performed the task twenty times with a fixed amount of force-feedback guidance from the wheel and ten times without; the guidance-as-needed group performed the task twenty times with a frequency and magnitude of guidance that was proportional to the magnitude and frequency of errors being made, and ten times without. In the retention trials without feedback, it was found that the guidance-as-needed group performed the task with the least amount of error, and during the tenth trial without feedback, both groups showed the same amount of error – the same amount as the last guidance trial of both groups respectively. The results of this study support both the use of a guidance-as-needed type of haptic augmented feedback for short-term learning (which may be difficult to administer for tasks of a different nature), and fixed guidance feedback that is followed by practice trials without guidance. Thus, literature supports the use of haptic guidance for the motor learning of complex motor tasks.

This collective body of literature makes it clear why an immediate positive performance effect on reducing lumbar spine motion was found by Carnegie et al. (2016) when using a dowel during the practice of sagittally symmetrical box lifts. Position-control-based guidance administered through concurrent haptic augmented feedback prevents errors during performance (Schmidt, 1991; Schmidt & Lee, 2005). However, although this leads to improved performance during acquisition and immediate retention tests, it has been shown to be detrimental to motor learning when it is provided through the entire practice (e.g., Scheidt et al., 2000; Weinstein et al., 1994), as postulated by the guidance hypothesis (Schmidt, 1991). It has been demonstrated that specifically for complex motor tasks (i.e., involving gross, whole-body multi-limb movements such as skiing; Wulf et al., 1998), position-control guidance can be beneficial to motor learning when it is administered early in the acquisition phase and practice without guidance is still given (e.g., Hagman, 1983). This may be because it is useful in providing a first-movement representation of the kinematic features that are required during the movement through providing the proprioceptive sensation (Féry & Morizot, 2000; Tsutsui & Imanaka, 2003), whilst allowing exposing learners to opportunities to calibrate to the environment by comparing their inherent feedback to the reference of correctness provided by the position-control-based guidance (Schmidt,
1991; Schmidt & Lee, 2005; Sigrist et al., 2013). Thus, position-control-based guidance has shown promise in rehabilitation settings to aid in the relearning of complex motor tasks (Marchal-Crespo & Reinkensmeyer, 2009), and may have potential for success in primary/secondary injury prevention programs, such as in movement (re)training interventions, where important kinematic features (i.e., maintaining an approximately neutral spine during lifting) are to be learned (e.g., Doss, Robathan, Abdel-Malek, & Holmes, 2018).

2.4.2 Terminal Knowledge of Performance Feedback

One of the most important categories of augmented feedback is knowledge of performance (KP), and is commonly provided by coaches and teachers to students in the form of verbal cues (Schmidt & Lee, 2005). They are internally-focused, where attention is drawn to movement patterns about how the skill is being performed (as opposed to KR, where the focus is on the outcome of the performance of the skill), most commonly focusing on processes that are difficult for the individual to perceive (Schmidt & Lee, 2005). Kinematic verbal feedback is a specific type of KP that is provided about the movement and/or coordination of body parts during the performance of a skill. Since lumbar spine displacement is a kinematic variable that is difficult for individuals to sense (Wilson & Granata, 2003), KP provided during practice may facilitate motor learning of spine-sparing lifting technique as it has been demonstrated for learning other complex motor tasks (e.g., Newell, Carlton, & Antoniou, 1990). Furthermore, the aim of the AUG intervention in this current study was not to teach an optimal lifting movement pattern because the lifting task parameters and context will vary in the workplace, but instead to stabilize a key feature of the movement during lifting of any type (i.e., neutral spine; Frost, Beach, McGill, & Callaghan, 2015), where KP may be especially effective. This is because it has been found to be most effective when it promotes active, problem-solving processes in the learner (Brisson & Alain, 1996a; 1999b). Thus, KP was provided verbally and terminally in this intervention (transfer effects are more likely to be observed when providing terminal KP versus concurrent KP; Armstrong, 1970) to aid in the learning process. This section will focus on how to administer KP to most effectively elicit learning outcomes during complex motor tasks.

Following again from the guidance hypothesis (previously described in the context of position-control-based guidance using haptic feedback in section 2.4.1; Schmidt, 1991), it appears as though KP is more effective for learning when it is provided only some of the time during acquisition, and especially so for complex tasks. For example, a study conducted by Weeks &
Kordus (1998) contrasted the learning effects when providing KP 100% of the time or 33% of the time during the practice of a soccer throw-in. Participants were all naïve (i.e., untrained) to the skill, and were aiming to hit a target that was distance of 75% of their maximum effort away. Experienced soccer coaches provided consistent KP based on one of eight, pre-determined kinematic variables of the task, such as releasing the ball just in front of the head. The acquisition phase consisted of 30 practice trials. There was a total of six learning tests: time (immediate, 24-hours, and 72-hours) by type (retention with the same target distance, and transfer with a new distance at 50% of their maximum effort). Evaluated by other experienced soccer coaches naïve to the purpose of the study, individuals were given a score out of eight based on form, based on the same kinematic variables that were focused on during acquisition. It was found that the group that practiced with 33% KP had higher form scores in acquisition and all six learning tests. The effect in the retention tests was greater than in the transfer tests for each time-point post-acquisition, with the largest effect size \( (d) \) being 1.79, 24-hours post-acquisition. The greatest effect amongst the transfer tests was for 1.34 for the immediate transfer test. The results of this study suggest that reducing the relative frequency of KP from 100% benefits the development of a response strategy that can be maintained when the performance context varies from the acquisition context. This finding was in-line with those of Young & Schmidt (1992), who had individuals perform a task on a coincident-timing apparatus. Participants had to look at a series of LEDs that illuminated in series from far to near and had to swing a lever to virtually hit the target LED that was closest to the participant. There was no reaction time needed in this task, as a consistent tone indicating 500ms until start was provided prior to the initiation of the first LED-lighting. This target represented a ball, and a virtual distance that they struck the ball was calculated using the instantaneous velocity the lever had as it “hit” the target LED and the spatial error (degrees) between the lever and the initiation of the target LED. In the first experiment, they determined that providing information about spatial kinematic variables (e.g., “make sure your backswing reaches a further position”) were superior to temporal variables (e.g., “begin backswing earlier relative to the first LED”) as individuals performed better in the retention test. Using this information in their second experiment, they compared the effects of providing spatial kinematic feedback (i.e., KP) at different schedules for 200 practice trials and tested the effects during the retention test. The first group received KP at the end of each acquisition trial, the average group received KP representing the average performance of the previous five trials on retention, and the faded group received KP as often as the average group, but after every 45-50 trials, the frequency
of feedback was reduced by five trials (i.e., KP is given once every ten trials for trials 46-96, once every fifteen trials for trials 97-137 and so on, until the minimum frequency of once every twenty trials was reached). It was found that the group that received KP in the faded-schedule had the highest score on both the 24-hour and one-week retention tests, which was greater than the average group, which in turn scored much better than the first group with 100% KP. Young & Schmidt (1992) first developed this research question to see if varying the schedule of KP influences motor learning in a way similar to KR, which has much more extensive research due to the fact that there are less methodological considerations to use KR (Weeks & Kordus, 1998). As scheduling KR in this manner also tends also to improve learning outcomes (e.g., Weinstein & Schmidt, 1990), Young & Schmidt (1992) argue that KP influences motor learning in ways parallel to KR and thus are operationally similar (Magill, 2001).

Self-controlled KP feedback schedules (i.e., learner-determined; providing KP when asked for by the learner) have also consistently been found to be superior to externally-controlled (i.e., randomly-created or pre-determined) feedback schedules for eliciting learning for performing novel motor tasks (e.g., Janelle, Barba, Frehlich, Tennant, & Cauraugh, 1997; Janelle, Kim, & Singer, 1995; Chiviacowsky & Wulf, 2002; 2005; Fairbrother, Laughlin, & Nguyen, 2012). An early study conducted by Janelle et al. (1995) was crucial in helping to determine this; participants were placed into either one of four intervention groups with different KP feedback schedules or a control group, and practiced underhand tosses of a golf ball towards a stationary target. The authors found that of the five groups, the self-controlled feedback group (who received KP feedback whenever they asked for it) was the only group who performed the task with significantly less error during an immediate retention test. This group of researchers continued to investigate this phenomenon and determined that not only is the self-controlled feedback group superior to summary KP, knowledge of results, and yoked control groups for learning to throw a ball at a stationary target with the non-dominant arm during a delayed retention test, but also required less KP than those with a rigid feedback scheduled (Janelle et al., 1997). These findings (amongst others) led to an influx of research looking to determine the mechanism for why self-controlled KP feedback better facilitates learning than externally-controlled schedules. Chiviacowsky & Wulf (2002) performed a similar study that yielded results in line with those from Janelle et al. (1995; 1997), but included a questionnaire to determine when individuals preferred to receive feedback. They determined that most individuals in the self-controlled feedback group asked for KP feedback only after trials they thought were “good”, with some individuals stating they either asked for
feedback after a “good” or “bad” trial, and no respondents stating that they only asked for KP after trials they thought were “bad”. The majority of the control group (with a fixed feedback schedule) believed they did not receive KP feedback after the correct trials, and would have preferred to only receive their KP feedback after “good” trials. From this, it was interpreted that the advantage of self-controlled feedback lies in receiving feedback as a function of their self-perceived level of performance (preferably self-perceived “good” trials), which was not available to learners with an externally-controlled feedback schedule (Chiviacowsky & Wulf, 2002; a finding reproduced by Fairbrother et al., 2012). In order to determine if this interpretation had merit, Chiviacowsky & Wulf (2005) followed up this work. They had two groups – both had self-controlled KP feedback, but one was only allowed to ask for KP feedback prior to a trial, whereas the other group was only allowed to ask for it after a trial. Those who were able to ask for KP feedback after a trial performed significantly better on a delayed transfer test, providing support to the hypothesis that self-controlled KP feedback schedules are more effective than externally-controlled KP feedback schedules because learners are afforded the ability to choose it based on their self-perceived performance (Chiviacowsky & Wulf, 2005). As such, the KP feedback provided in the AUG intervention of the current study was self-controlled (i.e., learner-determined) instead of being fixed.

It is important to recognize that although augmented feedback providing knowledge of result (KR) is an important and effective form of feedback that indicates task performance outcome (Schmidt & Lee, 2005), it was not utilized in the current study as KR is available to the participants 100% of the time due to the nature of a lifting task, and the outcome of the action is distinct from the motions that produced it. Specifically, the goal was to attenuate sagittal spine motion during the lifts to reduce the risk for developing LBDs (e.g., Marras et al., 1995), but the lift will likely be completed regardless of the form used. Furthermore, KP has been found to be more beneficial towards learning than KR when it comes to learning complex motor tasks, such as serving a volleyball (Zubiaur et al., 1999). In conclusion, supported by literature regarding how to best administer KP feedback, self-controlled terminal verbal KP feedback about the peak sagittal spine flexion angle was provided to participants with a faded, total frequency of 34% in the AUG intervention of the current study (described in section 3.2.6).
3 Methods

3.1 Study Participants

3.1.1 Recruitment and Inclusion/Exclusion Criteria

Male and female participants were recruited for this study. Individuals who had any previous or current experience working as a paramedic or have participated in formal lifting training programs (e.g., manual material/patient handling training, Olympic weightlifting, power lifting, or formal strength and conditioning training), were excluded from this study. This exclusion criterion was used to limit the possibility that participants had already learned and/or been currently training to lift without flexing the spine, and/or had experience performing the transfer tasks. Research has found that the rate of learning a motor task is influenced by previous experience with the task (e.g., Nembhard, 2000). Participants also had to be pain-free and have no known MSDs present in the previous twelve months (self-reported). This was assessed using the PAR-Q (Physical Activity Readiness Questionnaire: 2002 revision; Thomas, Reading, & Shephard, 1992; presented in Appendix A), where participants were excluded if they had answered “YES” to any question. Participants were also required to have the physical capacity to lift a load of approximately 45kg off the ground three times in a row (self-reported), as this was one of the tasks to be performed. To avoid the need to stratify the groups by age, participants had to be between the ages of 19-29 years of age by the end of their second data collection session so that they could provide informed consent and to ensure that age-related differences in motor learning was not a potential confounder in the study (e.g., Swinnen, 1998). For complete participation in the study, participants were compensated $15 at the end of both data collection sessions (for a total of $30), and they were entered in a draw for a chance to win an Apple iPad Mini (Apple, California, USA).

3.1.2 Sample Size

A power analysis was conducted to determine the sample size of n=22, with n=11 for both the DID and AUG intervention groups. The calculation was based on the assumptions of normal distribution, and used an equation from Rosner (2011). Power was calculated using conservative estimates of the pooled standard deviation and the average peak lumbar spine flexion values of both groups, based off data from a previous study incorporating similar lifting tasks (Carnegie et al., 2016; Chan, Welsh, Frost, & Beach, 2017). With the alpha level set to 0.05 for a two-tailed test, the beta set to 0.80, the required sample size to detect the expected differences was 11
individuals per group. Thirteen individuals were recruited to each group to account for an a priori estimated drop-out rate of 20% (due the requirement of two data collection sessions), thus leading to a total sample size of n=26. As no participants dropped out of the study, data from 26 individuals equally distributed between groups were included in the analyses.

3.1.3 Group Assignment

Individuals were placed in the AUG or DID group using stratified randomization, where the groups were balanced for sex. It is unknown if sex differences exist in the motor learning of lifting technique, but because sex differences in self-selected lifting strategies have been documented (e.g., Plamondon, Lariviè re, Denis, St-Vincent, & Delisle, 2014), groups were matched for sex. The lifts used in this study involved absolute starting heights (i.e., the same for every participant), thus taller individuals may have been more inclined to use a greater proportion of their available lumbar spine flexion range of motion to reach the lift origin position because it was relatively lower to them. In spite of this, height was not included as a factor because the study purpose was to compare the change in participants’ spine motion from baseline to two, post-intervention time points. Additionally, the initial height and mass of true paramedic lifting tasks are absolute (i.e., independent of the individuals performing the lift), thus the exclusion of height as a factor increases the ecological validity of the study. There are no known differences in participant mass influencing learning with haptic or KP augmented feedback nor spinal kinematics during lifting, so groups were not stratified by mass. In summary, participants were randomly selected to be in the DID or AUG group, with the sex matched.
3.2 Experimental Protocol

3.2.1 Experimental Design

The design of the study was a pretest-posttest randomized group comparison, with an additional posttest 7 days later (±1 day) to assess learning. A schematic representing the design of the study is presented in Figure 1. The first data collection session lasted approximately 90 minutes, while the second session lasted approximately 30 minutes (the approximate session durations accounted for the time associated with the placement/removal of markers and object setup for the lifting trials). The independent variables were group (two levels: DID or AUG group), time of testing (three levels: pre-; immediate post-; and delayed one-week post-intervention), and task (analyzed separately with three levels: box; medication bag lift; and backboard lift). A control group was not included because the comparison between a novel and traditional approach to movement (re)training was of greater interest than establishing the efficacy of either approach. The dependent variables were: duty cycle; peak sagittal spine flexion angle; peak sagittal spine flexion velocity; and peak sagittal spine extension velocity (discussed in detail in sections 3.3.2.3 and 3.4.1). Kinematics in the sagittal plane were selected to as the dependent variables because the interventions primarily aimed to influence sagittal plane motion only. Furthermore, these kinematic dependent variables represent well-established risk factors for the development of low back disorders on their own (Marras et al., 1995; Fathallah, Marras, & Parnianpour, 1998), and thus kinetic measures were not required. At time points immediate post-intervention and one-week post-intervention, the box lifting test was considered as the retention test whereas the medication

![Figure 1](image.png)

**Figure 1.** Schematic of the study design. Terms are represented by the following symbols. R: randomization; G: group; Did: didactic; Aug: augmented feedback; box photo: box lifting task (retention test); bag photo: medication bag lifting task (transfer test); backboard photo: paramedic backboard lifting task (transfer test); I: intervention.
bag and backboard lifts were considered as the transfer tests. Two transfer tests were selected because paramedics have various commonly performed strenuous tasks (e.g., Prairie & Corbeil, 2014), and because transfer of learning may be difficult to achieve for a task that involves a low-lying lift (explained in section 2.2.2). Additionally, it is typically undesirable to expose individuals to transfer tasks prior to the acquisition phase, but this was done in order to allow for the quantification of improvements in both transfer tasks between pre- and post-intervention. Because the primary research question focused on the effects of the two interventions on retention, the box lift was always the first task performed, and the subsequent two transfer tasks were randomized at every time point for every participant. Details of the study elements are presented in section 3.2: box lifting task in section 3.2.3; medication bag lifting task in section 3.2.4; paramedic backboard lifting task in 3.2.5; the AUG intervention in 3.2.6; and the DID intervention in 3.2.7.

3.2.2 General Procedure

Participants were recruited in the downtown Toronto area using a recruitment poster (Appendix B), word of mouth, and an online post on the Faculty of Kinesiology & Physical Education website. Interested individuals emailed the researcher, to which he responded with information regarding the study procedure, inclusion/exclusion criteria, location, physical requirements, appropriate clothing and footwear, compensation, consent procedures, and available time slots. Once individuals indicated that they were interested in participating and that they were not excluded by the criteria, they were scheduled for two data collections one-week (±1 day) apart. Participants were randomly placed into either group using a true random number generator (Random.org, Leinster, Ireland), whilst the number of males and females in each group were balanced. This was done by randomly assigning participants to groups, until one group reached a point where any additional individual to that group would make it impossible to balance both groups; once this point was reached, individuals were assigned (in the order in which they were recruited) to the appropriate intervention group to maintain an equal number of males and females between groups. On the first day, participants arrived at the Musculoskeletal Biomechanics Laboratory at the University of Toronto, read the information and consent form (Appendix C) and posed any questions they may have had, then signed the consent form and PAR-Q questionnaire (Appendix A). During this time, they were not informed about which intervention they were assigned to. Participants were then asked to change into their athletic shoes or bare feet,
compression shorts, and compression top or shirtless for males/compression top or sports bra for females.

A procedure had been developed in a previous study to facilitate an accurate and reproducible fitting of pelvis and thorax rigid bodies with attached passive reflective markers (instrumentation described in section 3.3.1), because a new harness system was developed to accommodate for a wider-range of body sizes (Zehr, 2017). The fitting procedure ensured that the superior border of the pelvis rigid body rested at the approximate level of the L5 vertebrae, and the inferior border of the thorax rigid body rested at the approximate level of the T12 vertebrae. The participants were asked to lie down on a massage plinth (Vichalla Supplies, Ontario, Canada) so that the T12 and L5 can be palpated and landmarked by the researcher using a water-soluble marker. The palpation technique was taught to the researcher by a physiotherapist from the David L. MacIntosh Sport Medicine Clinic at the University of Toronto, to minimize the chance that the incorrect vertebrae are marked. Once the T12 and L5 vertebrae were landmarked, the distance between the T12 and L5 vertebrae was measured. Subsequently, the participants’ masses were recorded using a Fitbit Aria bathroom scale (Fitbit, California, USA) and they were asked what age they would be by the second data collection session (i.e., their age one-week later). Height was obtained offline as the largest value measured in the various upright standing calibration trials. Once the participants were landmarked and their anthropometric data were collected, participants were then fit with the markers and rigid bodies.

A total of sixteen retroreflective markers were taped onto their skin/compression clothing, worn on a headband, or secured on with rigid body harnesses (diagram of marker setup is pictured in Figure 2). The seven markers secured to their head (x1), bilateral acromioclavicular joints (x2), bilateral iliac crests (x2), and bilateral greater trochanters (x2) were used for calibration purposes only. The remaining nine markers were used for tracking and were attached to two different rectangular rigid bodies: one for the thorax (x4) and one for the pelvis (x5). The thorax rigid body was strapped onto the participants’ mid-thoracic back in a pattern modelled after shoulder and sternum straps from a backpack, with the use of additional double-sided tape to minimize shifting. While the researcher held the thorax rigid body in the correct position, the participants were asked to buckle the straps together and adjust the tension appropriately (as guided by the researcher). The pelvis rigid body was secured onto the participants using a sacroiliac belt, with two additional between-leg straps that helped minimize shifting. Details on how participants were modelled using these markers is presented in section 3.3.2.2. Participants were then asked to perform several
warm-up movements for the following reasons: so that they could be physically prepared for the lifting tasks; any shifting of the markers could be corrected and preventative measures could be taken; and so that any issues with marker occlusion could be resolved prior to the start of data collection. The warm-up movements involved five of the each of the following in both directions: spine flexion-extension; spine lateral bending; and spine axial twisting. The study proceeded once the researcher was satisfied with the marker placements and the participants indicated that they were comfortable.

Figure 2. Diagram of marker setup. Sixteen total markers are used. Seven are used for calibration purposes only: one on the head (Head); two on bilateral acromioclavicular joints (RSH & LSH); two on bilateral iliac crests (RIC & LIC); and two on bilateral greater trochanters (RGT & LGT). Nine markers are used for tracking: four on the thorax (TRK1-4); and five on the pelvis (PEL1-5).
Next, a five-second static calibration trial was collected for each participant. Details on how calibration files were used is described in section 3.3.2.3. The calibration trial captured their relaxed upright standing posture, where participants were asked to stand “quietly” in anatomical position for five seconds. This file was checked for any missing data before continuing. If the trial was unsatisfactory (i.e., marker(s) were missing from frames and/or excessive movement from the participant), the calibration trial was redone. If the trial was satisfactory, the calibration-only markers were removed from the participants and they began their baseline lifting tests.

For the baseline tests, participants were given standardized verbal instructions of what was required in (but not how to perform) the box lifting task (section 3.2.3), the medication bag lifting task (section 3.2.4), and the paramedic backboard lifting task (section 3.2.5) right before each was performed. All participants began by performing the box lifting task. Then, the two transfer tests were randomized using a true random number generator (Random.org, Leinster, Ireland). Based off the results of the random number generator, participants performed either the medication bag or paramedic backboard lifting task, followed by the other. Following the completion of all lifting trials in this study (i.e., after all lifting tests and intervention sets) participants were asked for their rating of perceived exertion (RPE) using Borg’s CR-10 RPE scale, and only proceeded once they answered two or less on the scale to indicate they had a light or lesser RPE (Borg, 1990). If they responded with an RPE greater than two any time they were asked, they were given one additional minute of rest before they were asked again; this continued until they responded with an RPE of two or less. This was done in an attempt prevent fatigue from becoming a confounding factor in the study. For all participants in either group, the baseline tests were followed immediately by the training intervention.

Participants then underwent their respective interventions (to which they were assigned to prior to the first data collection session). Described in greater detail in section 3.2.6 and 3.2.7, individuals in both groups performed five sets of 10 box lifts as practice (i.e., constituting the acquisition phase of learning). Prior to beginning each set, participants were asked for their RPE with the same protocol previously-described. The data was sampled during the AUG intervention for feedback purposes but not saved (data was not sampled nor saved during the DID intervention).

Once the intervention was completed, a second standing offset trial was collected (without calibration markers), where participants were asked to stand quietly in anatomical position for five seconds (details on how offset trials were used is presented in section 3.3.2.3). Next, participants performed the immediate retention and transfer tests with a protocol identical to the baseline tests,
except with abbreviated (yet standardized) verbal instructions, an additional instruction to attempt to apply the principles they learned in their intervention to these lifts, and a re-randomized order for the two transfer tests. The data was checked to ensure completeness, followed by the removal of the rigid bodies. Participants received $15 compensation after signing a proof of payment sheet. At this point, they completed their first data collection session, and were told to continue with their week as normal and to return with the same clothing if possible.

One week (±1 day) later, participants returned to the lab. The procedure of the second data collection day was nearly identical to the first data collection day, minus the intervention and the immediate retention and transfer tests. Participants underwent the same marker-fitting procedure as the first data collection session, followed by the same warm-up movements. Their upright standing posture was collected again for calibration purposes, followed by the removal of the calibration-only markers. Participants were provided with the same standardized verbal instructions prior to each lifting task, with the additional instruction to attempt to apply the principles they have learned in their intervention to these lifts. Then, they underwent all three lifting tasks just as before, except with a re-randomized order for the two transfer tests. Once completed, the data was checked for completeness, the rigid bodies were removed, and individuals were given a quick debrief of the study. Participants received an additional $15 compensation and were entered in the Apple iPad Mini draw for an after signing a proof of payment sheet. At this point, the participants had successfully completed the study.

3.2.3 Box Lifting Task

For the box lifting task (pictured in Figure 3), participants lifted a milk crate loaded with barbell plates that had a combined mass of 6kg with the dimensions of 33 x 33 x 28cm (length x width x height). This mass was chosen for use during the practice trials (i.e., acquisition phase) in the interventions, baseline, immediate- and delayed-retention tests because when the initial height (28cm), the final height (minimum height is standing tall with arms extended, i.e., knuckle height), the carrying distance (0m) and the lifting frequency (approximately 35 lifts/minute) was taken into account, the Snook table indicated that this load is deemed acceptable for 90% of males and females (Snook & Ciriello, 1991). Furthermore, both the dimensions and the load were selected because the demands differ from the transfer task (i.e., the medication bag and paramedic backboard lifts), thus allowing the transfer tasks to reveal the generalizability of the learned movement feature due to the intervention (e.g., Weinstein et al., 1994; Schmidt & Young, 1987). Thus, this task was
considered the retention task immediate post-intervention and one-week post-intervention (i.e., delayed retention).

Participants were asked to lift the box using both handles up from the ground to a tall, standing position with a self-selected arm position (knuckle height was the minimum height; Lavender et al., 2003), back down to the ground to release the box, then stand tall. This constituted one lift, and they were asked to perform three lifts per trial at a self-selected speed. Aside from being told not to stagger their feet and to use two hands on the handles, participants were instructed to use a self-selected technique. If a participant failed to complete a lift, did not reach the tall standing position during or after the lift, the trial was stopped and redone after the individuals had sufficient rest to give a response of two or less on the Borg CR-10 RPE scale.

![Image](image1.jpg)

**Figure 3.** An individual performing the box lifting task.

### 3.2.4 Medication Bag Lifting Task

The medication bag lifting task (pictured in Figure 4) was a transfer task that differed in comparison to the box lifting task. Specifically, the physical appearance, mass, starting height, coupling, and rigidity of the handle differed. This task was chosen because it is one of the commonly-performed paramedic tasks that have been rated as being physically demanding (Coffey et al., 2016; Prairie & Corbeil, 2014). Additionally, there have been no administrative changes that have reduced the frequency of using this bag (Coffey et al., 2016). Participants lifted the medication bag (Medtech, British Columbia, Canada) with the dimensions of 62 x 16 x 26cm (length x width x height) and mass of 8.7kg (loaded with barbell plates and spacers made of cardboard to minimize shifting). The participants lifted the bag using two 1000D Cordura nylon straps. The straps were secured together with Velcro and rested on top of the bag prior to the lifts.
When grabbed and lifted by the participant, they extend approximately 15 cm above the top of the bag. The bag did not carry medical supplies; instead, the bag itself weighed 0.57 kg, and barbell plates and cardboard spacers (to avoid any shifting of mass) were placed inside to contribute an additional 8.13 kg, placed evenly along the length of the bag. The dimensions of the medication bag were selected to emulate a real medication bag that is used in the field, and the mass was selected as the average mass of the medication bags measured across seven different paramedic services across Ontario (Coffey et al., 2016).

![Image](image.png)

**Figure 4.** An individual performing the medication bag lifting task.

Prior to the trial, participants were told to place the bag wherever they desired relative to them. Thus, there was no designated starting or ending location for the bag; this was a decision left to the participant. Precise placements were not asked of the participants because this demand has been found to influence individuals’ movement behaviour during lifting (Beach, Coke, & Callaghan, 2006). Participants were instructed to use one hand only on the handles, but that they did not have to use the same hand throughout the trial nor throughout the study. Aside from that, they were told to use self-selected technique, including to place their feet however they desired. Participants were asked to lift the medication bag up from the ground to a tall, standing position with a self-selected arm position (knuckle height was the minimum height; Lavender et al., 2003), back down to the floor to release the medication bag, and stand tall. This constituted one lift, and they were asked to perform three lifts per trial at a self-selected speed. If a participant failed to complete a lift, did not reach the tall standing position during or after the lift, the trial was stopped and redone after the individuals had sufficient rest to give a response of two or less on the Borg CR-10 RPE scale.
3.2.5 Paramedic Backboard Lifting Task

The paramedic backboard lifting task (Figure 5) was a transfer task that differed in comparison to the box lifting task. Specifically, the physical appearance, mass, starting height, coupling, and speed of lift differed. Additionally, this task was a joint-action task involving coordination between two individuals. This task was performed with the same researcher in both interventions, who always lifted the foot-end of the backboard. Although it is possible that participants may have used visual cues from the researchers to guide their lifting, this method of performing the task was selected to increase the applicability of the task, as the true lift is conducted by paramedics with both sides lifted up at the same time (Lavender et al., 2000b). The task itself was selected because it is one of the commonly-performed paramedic tasks where the spine postures and loading contribute to an adverse risk of sustaining LBDs (e.g., Lavender et al., 2000a; 2000b; Coffey et al., 2016; Prairie & Corbeil, 2014). Additionally, no ergonomic interventions have been introduced to change how this task is performed, unlike the raising and lowering of stretchers that have been altered by the introduction of motorized stretchers (Armstrong et al., 2017), or the patient transfers from the bed to the stretcher to the gurney which have been altered by low-friction boards (Lavender et al., 2007).

Figure 5. An individual performing the paramedic backboard lifting task with a researcher. Participants always lifted the head-end of the backboard; the same researcher lifted the foot-end of the backboard with all participants.
Strapped to the 9kg wooden backboard with a length of 1.83m and handles elevated 0.03m off the ground (donated from the Hastings-Quinte Paramedic Services) was a 73.5kg mannequin (Simulaids, New York, USA) to represent the approximate mass of an average adult male, with a height of 1.80m and shoulder width of 0.46m (average adult weight in an industrial population is estimated to be 774N; Marras & Kim, 1993). Together, the backboard and the mannequin weighed 809.3N, and the true weight that participants lifted was slightly greater than half (as the mannequin centre-of-mass is closer to the head-end). Participants were instructed to lift with a self-selected speed that the researcher would attempt to match to the best of his ability, and were instructed to give a “…3, 2, 1, lift…” countdown prior to the initiation of lifting the load off the ground (so that the speed of the participants’ lifts could be closely matched). Participants were asked to lift the head-end of the backboard from the ground to a tall, standing position with a self-selected arm position (the final height of the backboard was matched by the researcher), back down to the ground to release the backboard, then stand tall. This constituted one lift, and they were asked to perform three lifts per trial. Aside from being told not to stagger their feet and to use two hands on the handles, participants were instructed to use a self-selected technique. If a participant failed to complete a lift, did not reach a tall standing position during or after the lift, the trial was stopped and redone after the individuals had sufficient rest to give a response of two or less on the Borg CR-10 RPE scale.

3.2.6 Augmented Feedback (AUG) Intervention

The augmented feedback (AUG) intervention consisted of five sets of ten repetitions of the box lifting task, with a combination of augmented feedback and individualized coaching cues provided by a blinded research assistant. The schedule of augmented feedback administration is shown in Table 1. Fifty practice lifts were chosen for this intervention (and subsequently the DID intervention) because the successful learning of a complex motor skill with augmented feedback has been observed with as little as 30 practice repetitions (Weeks & Kordus, 1998). Although additional practice trials may further increase the likelihood of successful learning (e.g., Young & Schmidt, 1992), 50 lifts were selected to ensure learning was still possible, whilst reducing the potential for fatigue. Including various lifting tasks in randomized order during the acquisition phase to create contextual interference may have also been beneficial in facilitating learning (i.e., random practice; Schmidt & Lee, 2005), but was not implemented in either group so that the interventions’ effects on retention and transfer could specifically be examined.
For the first set of 10 lifts, participants were informed by the research assistant that they would be learning to lift in a recommended manner by reducing lumbar spine motion used (McGill, 2004), and that they would be practicing with a dowel (dimensions: 3cm diameter x 150cm height) used as a tactile cue in the first set. This form of tactile cuing is called position-control guidance, and it has been found to facilitate motor learning when it is administered early in the acquisition phase, and when practice without guidance is still present (e.g., Hagman, 1983; see section 2.4.1). Pictured in Figure 6, the research assistant held the dowel to the participants’ back with two points of contact throughout the lifts: the mid-thoracic spine and the sacrum. The participants were instructed to attempt to maintain both points of contact with the dowel throughout the lifts to the best of their ability. A rough, two-second rest time between lifts was maintained by the research assistant, who indicted when to begin the next lift. This was done to attempt to match the between-lift rest time in both the DID and AUG intervention; however, this two-second rest was not strictly adhered to in the AUG intervention due to the requirement of feedback from the research assistant. During this first set, the research assistant provided verbal coaching cues at his discretion about foot position, knee angle, spine flexion, or arm/shoulder position. Once this set was completed, the participants moved onto the next block after a two-minute break, followed by the standardized RPE-check (described in section 3.2.2).

Table 1. Schedule of augmented feedback administration in the AUG intervention. KP: terminal knowledge of performance feedback.

<table>
<thead>
<tr>
<th>Set #</th>
<th>First 10 lifts with dowel + individualized coaching cues</th>
<th>5x opportunities for KP Feedback</th>
<th>4x opportunities for KP Feedback</th>
<th>3x opportunities for KP Feedback</th>
<th>2x opportunities for KP Feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>First 10 lifts with dowel</td>
<td>5x opportunities for KP Feedback</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>5x opportunities for KP Feedback</td>
<td>4x opportunities for KP Feedback</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>4x opportunities for KP Feedback</td>
<td>3x opportunities for KP Feedback</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>3x opportunities for KP Feedback</td>
<td>2x opportunities for KP Feedback</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>2x opportunities for KP Feedback</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
For the subsequent four sets of lifting repetitions, the participants were no longer exposed to the dowel. Instead, they were provided with terminal, verbal knowledge of performance (KP) feedback for 35% of the remaining 40 lifts, with the frequency faded in the following manner: KP was available 5, 4, 3, and 2 times for sets 2, 3, 4, and 5 respectively, for a total of 14 times (shown in Table 1). Additionally, the KP feedback was self-controlled, meaning that participants asked for KP feedback after any lift of their choice. Participants were specifically instructed to ask for KP feedback “whenever you’d like”, and this instruction was important to ensure participants were not biased to ask for feedback exclusively after self-perceived “good” or “poor” lifts. Any or all remaining feedback not yet used in a set was given automatically at the end of that set; for example, if a participant had two times left to ask for feedback in a set but did not use them, they would have automatically received KP feedback on lifts 9 and 10 in that set. Research has shown that providing terminal KP as augmented feedback during the practice of a complex motor skill for 33% of the 30 practice trials positively influenced learning outcomes with improved retention and transfer over 24- and 72-hours post-acquisition compared to those receiving KP 100% of the time (Weeks & Kordus, 1998). Additionally, Young & Schmidt (1992) demonstrated that individuals practicing with KP in a faded-schedule had a higher score on both the 24-hour and one-week retention tests than those with the same amount of KP in a fixed-schedule and those with 100%
KP. Giving feedback only when the learners ask for it (i.e., self-controlled feedback) has also been
demonstrated to improve learning outcomes on delayed transfer tests (Chiviacowsky & Wulf,
2005; 2002). A closer look at the research supporting the design of this feedback schedule is
presented in section 2.4.

The KP feedback was administered in the form of standardized phrases from the research
assistant, conveying qualitative information about how much sagittal spine flexion was observed
on that lift. These phrases are presented in Table 2. This was accompanied by information
regarding whether or not there had been more or less spine flexion in that lift compared to the last
lift that they had asked for feedback. The researcher on the computer signaled this information to
the research assistant using hand gestures after the participant asked for feedback. Peak sagittal
spine flexion angles were calculated real-time in Visual3D (process described in section 3.3.2.4).
When KP feedback was asked for (but not at other times), the research assistant may have also
provided individualized coaching cues regarding foot position, knee angle, spine flexion, or
arm/shoulder position, at his discretion. Again, participants received two-minutes of rest between
sets followed by the standardized RPE-check (described in section 3.2.2). Once they had
completed the fifth set, they completed the AUG intervention.

Table 2. Qualitative feedback provided by the research assistant and the corresponding peak
spine flexion angle observed on the most recently-performed lift.

<table>
<thead>
<tr>
<th>Spine flexion angle</th>
<th>Qualitative feedback given</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 10°</td>
<td>“Excellent. Keep this up!”</td>
</tr>
<tr>
<td>10-20°</td>
<td>“This was good, and there is still room to improve.”</td>
</tr>
<tr>
<td>21-35°</td>
<td>“Not bad, but keep trying to resist flexion even more.”</td>
</tr>
<tr>
<td>36-50°</td>
<td>“Your spine was flexed during that lift.”</td>
</tr>
<tr>
<td>&gt; 50°</td>
<td>“There was a lot of spine flexion during that lift.”</td>
</tr>
</tbody>
</table>

3.2.7 Didactic (DID) Intervention

For the participants in the didactic (DID) group, the intervention began with a blinded
research assistant giving a brief slideshow presentation based on materials adapted from the current
Occupational Health Clinics for Ontario Workers Inc. (OHCOW) Guidelines for the Prevention of
Back Injuries in Paramedics, developed by OHCOW, the Greater-Sudbury Emergency Services,
and the CUPE 4705 Union (the slideshow presentation is included in Appendix E). Module 1:
Understanding Your Back, and Module 2: Preventing Injuries were selected because they are the parts of the current guideline provided to paramedics working in Ontario that incorporate educational materials that are similar to those provided in the first back school and subsequent lifting training programs (Forssell, 1981; Garcia et al., 2011). For example, these two modules contain information on epidemiology (i.e., risk factors, injuries rates and types), treatment options, spinal anatomy & physiology, ergonomic principles, and the biomechanics of lifting techniques. The remaining module (Module 3: Challenges to Lifts/Transfers) was not included in the presentation for time purposes, and because the information pertains to specific environmental challenges faced by paramedics that were not deemed relevant to the environmental conditions of the biomechanics laboratory. The slideshow presentation required the participant to listen for approximately twelve minutes while seated at a table. They were given the option of standing for the presentation; however, no participants chose this option. They were encouraged to take notes during the presentation and were given an opportunity at the end to ask questions. The presentation setup is presented in Figure 7.

![Figure 7](image)

**Figure 7.** A participant listening to the DID intervention presentation given by a blinded research assistant. Participants were given the option to stand if they desired.

Once participants finished listening to the presentation, they began the practical component of the DID intervention, which was designed to match the AUG intervention in terms of lifts per set, number of practice lifts allowed, and between-lift rest time (see section 3.2.6). A standardized verbal instruction to “attempt to apply the principles you have learned in the intervention to these practice lifts to the best of your ability” was provided prior to the start of the first set. They performed five sets of 10 box lifts with a self-selected speed (the same box lifting task used in the baseline, immediate post-intervention and one-week post-intervention tests; section 3.2.3) with
two seconds of rest between lifts. This rest time was enforced using an audible “beep” sound from the researcher indicating when to begin the next lift. The researcher roughly identified the end of a lift with visual observation, began a two second count on a computer timer, then activated the audible “beep” signal on an iPhone using an application called Bleep! (BrennanMoyMedia, USA). Participants were given two minutes rest between sets, after which they were asked for their RPE. The next set commenced if individuals responded with an RPE of two or less, and additional rest time was given if their RPE was greater than two. No demonstration, additional instruction, or individualized feedback was provided throughout this intervention, and no data were collected. Once the 50 practice lifts had been performed, they had completed the intervention.

Considering the DID intervention included educational materials combined with a practice component without individualized feedback, the design of this intervention resembled many current movement (re)training interventions (e.g., Lønn et al., 1999; Garcia et al., 2011; Cecchi et al., 2010) that have been found to have limited success in reducing low back pain reporting (e.g., Hignett, 2003; Martimo et al., 2008; Daltroy et al., 1997; see section 2.3.2).

### 3.3 Data Collection and Processing

The following sections describe what was used to collect the data, how it was conditioned, and how the dependent variables were calculated.

#### 3.3.1 Data Collection and Instrumentation

Sixteen retroreflective markers were used to quantify spine motion (description and diagram of marker setup is presented in section 3.2.2, Figure 2). The thorax rigid body was constructed from wooden doweling and was strapped onto the participants’ mid-thoracic back in a pattern modelled after shoulder and sternum straps from a backpack, with the use of additional double-sided tape to minimize shifting. The pelvis rigid body was constructed from stainless steel and was secured to a sacroiliac belt worn by participants, which had two additional between-leg straps attached to help minimize shifting (Zehr, 2017). Marker position data were captured using an eight-camera optoelectronic motion capture system (Oqus 100, Qualisys, Bohuslän, Sweden) sampling at 60Hz. An approximate 2.5m x 2.0m x 1.9m (length x width x height) space was calibrated prior to each data collection session using the wand calibration method (as per manufacturer’s instructions). Calibrations were accepted if all eight cameras captured equal or greater than 1000 data points with an average residual error equal or lesser than 0.9mm after the
60-second calibration period; if this criterion was not met, the calibration was rejected and the wand calibration was repeated until the criteria was met. This criterion was established by following manufacturer’s recommendations, and it was determined during pilot testing that these aforementioned thresholds consistently led to no marker dropout during collections.

The optoelectronic motion capture system was connected to a data collection computer, and the data was collected, labelled, and exported to .c3d files using Qualisys Track Manager v2.15 software (Qualisys AB, Bohuslän, Sweden). Visual3D v6 and Visual3DServer software (C-Motion Inc., Maryland, USA) were used to calculate the terminal KP feedback in real-time for the AUG intervention (section 3.3.2.4). Bleep! (BrennanMoyMedia, USA) was used to provide an audible “beep” signal in the DID intervention. Random.org (Random.org, Leinster, Ireland) was used for random number and list generation throughout the study (e.g., for randomized group selection and the order of the transfer tasks). The data included in statistical analyses were processed offline in Visual3D v6 (C-Motion Inc., Maryland, USA).

Borg’s CR-10 RPE scale (Borg, 1990; Appendix D) was used to assess participants’ perceived physical exertion between the tests and acquisition trials in this study. A self-reported measure of perceived exertion was chosen to control the effect of fatigue because fatigue is a complex concept with psychophysical underpinnings that cannot be objectively quantified (Borg, 1990). Thus, a self-reported assessment of RPE sufficed for the purpose of controlling fatigue.

3.3.2 Data Processing

3.3.2.1 Filtering

All raw marker trajectories were smoothed using a zero-lag (effective 4th order) Butterworth low-pass filter (Winter, Sidwall, & Hobson, 1974) with a cut-off frequency of 3Hz. This filter was applied to the raw marker trajectory data in Visual3D v6 (C-Motion Inc., Maryland, USA) before any kinematic modeling procedures were employed. Previous projects conducted at the University of Toronto MSK Biomechanics lab measuring spinal motion during the performance of similar lifting tasks utilized a low-pass cut-off frequency of 3Hz (Carnegie et al., 2016; Chan et al., 2017; Zehr, 2017), which was supported based on the results of residual analyses (Winter, 2009) performed on similar lifting tasks (Beach, Coke, & Callaghan, 2006).
3.3.2.2 Linked-segment Kinematic Model

A two-segment kinematic-only model was constructed of participants’ thorax and pelvis in Visual3D v6 (C-Motion Inc., Maryland, USA). Using participants’ upright standing trial (in anatomical position), a model comprised of two pelvis segments and one thorax/abdomen segment was created. The first pelvis segment used the bilateral iliac crests and greater trochanters as calibration markers and tracked with the five markers on the pelvis rigid body; the second virtual pelvis segment used the same calibration markers but tracked with the four markers on the thorax rigid body (used for dependent variable calculations; section 3.3.2.3). The thorax/abdomen segment used the bilateral acromioclavicular joints and iliac crests as calibration markers and tracked with the four markers on the thorax rigid body. This model was built twice for each participant: one for each upright standing calibration trial taken at the start of both data collection days. These were then used to process the data from that respective day: real-time feedback calculations (for the AUG group only) and lifts on the first day; lifts on the second day. This process effectively treated each individuals’ upright standing posture as zero degrees of sagittal spine flexion.

3.3.2.3 Calculation of Dependent Variables

At the end of both data collection days, the raw data were labelled and exported to .C3D files using Qualisys Track Manager v2.15 software (Qualisys AB, Bohuslän, Sweden). A workspace was created in Visual3D v6 (C-Motion Inc., Maryland, USA) where all files were imported and the marker trajectories were filtered (section 3.3.2.1). The kinematic-only linked-segment model was then created using the upright standing calibration trial and applied to all files (section 3.3.2.2); thus, a neutral spine curvature with natural lumbar lordosis was assumed to be the zero degrees of sagittal plane spine flexion. The spine displacement data was then calculated for all data files, using a Cardan/Euler decomposition sequence of mediolateral, anterior/posterior, axial, where the virtual pelvis segment (tracked with the thorax markers) was referenced to the pelvis segment (tracked with the pelvis markers).

Start and end events were then manually created to mark the beginning and end of each lift phase (of the lift/lower cycle) using visual observation of the signal aided by visual observation of the Visual3D animation. The start events were created when there was a steep increase in sagittal spine displacement angle accompanied by the animation showing the initiation of a motion that resembled lifting; the end events were created when the sagittal spine displacement angle plateaued
around where it began before the lift accompanied by the animation showing the end of a lifting motion. The lowering phase (i.e., when the individual lowers the box, medication bag, or backboard to the ground, then stands tall) was not processed. Three start and end events were created for each trial due to three lifts in a trial.

The following step was only done with day one data. The average sagittal spine displacement value of upright standing offset trial (collected immediately after the intervention without calibration markers) was extracted and subtracted from the sagittal component of all post-intervention trials. This was done to correct for any shifting that may occurred during the fifty practice lifts in either intervention, and effectively treated the post-intervention standing position as zero degrees of sagittal spine flexion for all lifting trials that ensued. This correction procedure was included after it was revealed in pilot testing that regardless of the precautions taken to prevent sacroiliac belt shifting, it was still likely to occur after fifty lifts.

Next, the first derivative of the sagittal component of the spine flexion displacement signal was taken in all trials to calculate sagittal spine velocities. Within previously-made start and end events, the duty cycle (time between start and end events), peak sagittal spine flexion angle (global maximum), peak sagittal spine flexion velocity (global maximum) and peak sagittal spine extension velocity (global minimum) values were extracted. This resulted in three values per dependent variable per lifting trial, and they were averaged to represent the peak value of that trial. Thus, after this reduction, there was one value for each dependent variable per trial. A researcher error in data collection resulted in the loss of the first two lifts from two participants’ baseline bag lift trial; in this situation, the values of the dependent variables in the third lift were duplicated twice to represent the missing lifts. The data were exported an ASCII file.

### 3.3.2.4 Real-time Feedback Calculation for the AUG Intervention

The sagittal spine flexion angle throughout the AUG intervention was calculated real-time in Visual3D and signaled to the research assistant using hand signals when required. In order to do this, Qualisys Track Manager (Qualisys AB, Bohuslän, Sweden) was sampling at 60Hz and actively labelling markers using an AIM (automatic identification of markers) model developed for this specific dataset. Labelled marker trajectory data was streamed into Visual3DServer (C-Motion Inc., Maryland, USA), where it was streamed into Visual3D (C-Motion Inc., Maryland, USA) using an external plug-in. Prior to the intervention, a linked-segment model of the participant was created in the Visual3D workspace, which allowed for the use of a real-time pipeline to
calculate the sagittal spine flexion angle. This displacement data was plotted with time. When KP feedback required, the researcher on the computer then categorized the visually observed peak spine flexion angle value from the graph into one of five ranges (shown in section 3.2.6, Table 2) and gestured this information to the research assistant using hand signals. It is important to note that although this real-time feedback was originally also desired for the first dowel-guided set, this was not possible because it was found during piloting that the dowel could not reliably be used on the back without partially/fully occluding the participants’ markers.

3.4 Statistical Analyses

3.4.1 Summary of Dependent Variables

The dependent variables in this study included the duty cycle (s), peak sagittal spine flexion angle (°), peak sagittal spine flexion velocity (°/s), and peak sagittal spine extension velocity (°/s) during the lift phase of the lift/lower cycle only. Additional participant characteristic dependent variables were participants’ age (years), mass (kg), height (m), and time between sessions (hrs).

3.4.2 Statistical Tests

Statistical analyses were performed using R-Studio v1.1.442 (RStudio, Massachusetts, USA) and Microsoft Excel 2016 (Microsoft, Washington, USA). Data visualizations were created using Microsoft Excel 2016 (Microsoft, Washington, USA). The alpha level was set to $\alpha=0.05$ for all statistical tests conducted. Participant characteristics (i.e., age, mass, height, and time between sessions) and performance in all tasks at baseline were compared between groups using unpaired Student’s t-tests (two-tailed). Means and standard deviations were also calculated.

General linear models (GLMs) with one between-participant factor (group = “DID”, “AUG”) and one within-participant factor (time = “time 1”, “time 2”, “time 3”; corresponding respectively to baseline, immediate post-intervention, and delayed one-week post-intervention) were used to compare dependent variables (i.e., duty cycle, peak spine flexion angle, peak spine flexion velocity, and peak spine extension velocity). A separate GLM was used to analyze each dependent variable for each task (i.e., twelve GLMs were conducted). Partial eta squared values were also calculated in the model for each factor and interaction to provide an effect size estimate. This statistical approach was selected due to the conservative and robust nature of the analysis (i.e., smaller probability of false positives). The dependent variables and tasks were analyzed separately because there was no interest in examining the relationship between the dependent
variables, nor the performance of a task at one time point to another task at the same or other time points. These models were not corrected; although the velocity dependent variables are calculated using displacement data, they were assumed to be sufficiently independent of each other. That is, it was assumed that the peak sagittal spine flexion velocity does not directly/strongly depend on the peak sagittal spine flexion angle observed.

Post-hoc analyses were conducted on the highest-level effect of each model using paired and unpaired Student’s t-tests (two-tailed). Specifically, when a significant time-by-group interaction effect was found, eight comparisons were made. Six within-group comparisons were conducted with paired t-tests in both AUG and DID groups: time 1 versus 2; time 1 versus 3; and time 2 versus 3. Additionally, two between-group comparisons were conducted with unpaired t-tests to compare the differences in dependent variable magnitude between times 1 and 2 and between times 1 and 3. Differences in dependent variable magnitude were calculated as difference scores; for example, the magnitude of the dependent variable at time 2 was subtracted from time 1 to yield the time 1 to 2 difference. If the highest-level significant effect was time, three comparisons were made for the entire sample (group was disregarded): time 1 versus 2; time 1 versus 3; and time 2 versus 3. Group was never the highest-level significant effect. Multiple post-hoc comparisons were corrected using the Benjamini-Hochberg (BH) correction procedure (Benjamini & Hochberg, 1995) with a false discovery rate set to 5% (Q-value = 0.05). The BH correction procedure controls the false discovery rate. A correction method was selected because multiple comparisons warrant protection against type I errors. Furthermore, control over the false discovery rate was selected over control of familywise error rate (e.g., offered by Bonferroni corrections) because the false discovery rate is a less stringent condition than the family-wise error rate, thus increasing power in the comparisons (Benjamini & Hochberg, 1995; Thissen, Steinberg, & Kuang, 2002).
4 Results

4.1 Participant Characteristics

Complete datasets from all 26 individuals who participated were included in the statistical analyses, with n=8 males and n=5 females per group (i.e., n=13 participants per group). Participants characteristics of both groups are presented in Table 3. No significant baseline differences between groups were observed for age ($t(24)=0.534$, $p=0.598$), mass ($t(24)=0.668$, $p=0.511$), or height ($t(24)=0.354$, $p=0.727$). Additionally, there was no difference in time between data collection session start-times between the intervention groups ($t(24)=1.432$, $p=0.165$).

| Table 3. Participant characteristics at baseline. Values are presented as mean (SD). |
|---------------------------------|----------------|----------------|
| Age (years)                     | DID group      | AUG group      |
|                                 | 22.9 (2.7)     | 23.5 (3.2)     |
| Mass (kg)                       | 71.3 (16.6)    | 67.8 (9.2)     |
| Height (m)                      | 1.70 (0.07)    | 1.71 (0.09)    |
| Time between sessions (hrs)     | 158.7 (17.0)   | 168.2 (16.8)   |

4.2 Duty Cycles across all Tasks

No baseline differences between intervention groups were observed in duty cycle for the box lifting task ($t(24)=0.256$, $p=0.800$), medication bag lifting task ($t(24)=0.362$, $p=0.721$), or paramedic backboard lifting task ($t(24)=0.155$, $p=0.878$). A significant interaction effect was observed in duty cycle during the box lifting task only ($F_{2,48}=3.659$, $p=0.033$, $\eta^2_p=0.132$). A significant main effect of time was observed in duty cycle during the bag lifting task ($F_{2,48}=4.396$, $p=0.018$, $\eta^2_p=0.155$). No significant interaction or main effects were observed in duty cycle during the backboard lifting task ($p \geq 0.336$), thus no post-hoc analyses were performed on this task. The results for both intervention groups and all three tasks are presented in Figure 8. The results of the post-hoc analyses are presented in sections 4.2.1 to 4.2.2.
Figure 8. Results of the duty cycle analyses for all lifting tasks: A) Box lifting task; B) medication bag lifting task; C) paramedic backboard lifting task. The error bars indicate standard error of the mean (SEM). * indicates significant difference between time-points across both groups.
4.2.1 Duty Cycles in the Box Lifting Task

For duty cycle time in the AUG group during the box lifting task, no significant differences were observed between the baseline and immediate retention tests ($t(12)=0.944$, BH-corrected $p=0.364$), between the baseline and delayed retention tests ($t(12)=2.326$, BH-corrected $p=0.102$), or between the immediate and delayed retention tests ($t(12)=1.275$, BH-corrected $p=0.302$).

For duty cycle time in the DID group during the box lifting task, no significant differences were observed between the baseline and immediate retention tests ($t(12)=2.659$, BH-corrected $p=0.083$), between the baseline and delayed retention tests ($t(12)=1.148$, BH-corrected $p=0.314$), or between the immediate and delayed retention tests ($t(12)=1.506$, BH-corrected $p=0.302$).

The reductions in duty cycle time that occurred during the time between the baseline and immediate retention tests were not different between groups ($t(24)=1.843$, BH-corrected $p=0.155$). Additionally, the reductions in duty cycle time that occurred during the time between the baseline and delayed retention tests were not different between groups ($t(24)=2.592$, BH-corrected $p=0.083$).

4.2.2 Duty Cycles in the Medication Bag Lifting Task

For duty cycle time during the bag lifting task across both intervention groups, a significant difference was observed between the baseline and delayed transfer tests (0.31s increase; $t(25)=3.099$, BH-corrected $p=0.014$) No difference was observed between the baseline and immediate transfer tests ($t(25)=1.997$, BH-corrected $p=0.085$) and between the immediate and delayed transfer tests ($t(25)=0.731$, BH-corrected $p=0.472$).

4.3 Retention: Box lifting task

No baseline differences between intervention groups were observed during the box lifting task for peak spine flexion angle ($t(24)=1.389$, $p=0.178$), peak spine flexion velocity ($t(24)=1.042$, $p=0.308$), or peak spine extension velocity ($t(24)=1.337$, $p=0.194$). A significant interaction effect was observed for the box lifting task in peak spine flexion angle ($F_{2,48}=3.826$, $p=0.029$, $\eta^2_p=0.137$), peak spine flexion velocity ($F_{2,48}=5.257$, $p=0.009$, $\eta^2_p=0.180$), and peak spine extension velocity ($F_{2,48}=5.520$, $p=0.007$, $\eta^2_p=0.187$). The results for both intervention groups are presented in Figure 9. The results of the post-hoc analyses are presented in sections 4.3.1 to 4.3.3.
Figure 9. Results of the kinematic analyses for the box lifting retention task: A) Peak spine flexion angle; B) peak spine flexion velocity; C) peak spine extension velocity. The error bars indicate standard error of the mean (SEM). *indicates significant difference between time-points in AUG group; #indicates significant difference between time-points in DID group; †indicates significant difference in baseline-to-immediate retention test reduction between groups; ‡indicates significant difference in baseline-to-delayed retention test reduction between groups.
4.3.1 AUG Intervention Group

For peak spine flexion angle in the AUG group, a significant difference was observed between the baseline and immediate retention tests (31.1° decrease; t(12)=5.469, BH-corrected p<0.001), between the baseline and delayed retention tests (18.7° decrease; t(12)=4.152, BH-corrected p=0.002), and between the immediate and delayed retention tests (12.4° increase; t(12)=2.942, BH-corrected p=0.020).

For peak spine flexion velocity, a significant difference was observed between the baseline and immediate retention tests (42.7°/s decrease; t(12)=5.812, BH-corrected p<0.001), between the baseline and delayed retention tests (33.3°/s decrease; t(12)=4.975, BH-corrected p=0.001), and between the immediate and delayed retention tests (9.4°/s increase; t(12)=2.823, BH-corrected p=0.021).

For peak spine extension velocity, a significant difference was observed between the baseline and immediate retention tests (41.8°/s decrease; t(12)=7.585, BH-corrected p<0.001), between the baseline and delayed retention tests (28.3°/s decrease; t(12)=4.366, BH-corrected p=0.004), and between the immediate and delayed retention tests (13.5°/s increase; t(12)=3.140, BH-corrected p=0.014).

4.3.2 DID Intervention Group

For peak spine flexion angle in the DID group, a significant difference was observed between the baseline and immediate retention tests (17.1° decrease; t(12)=5.798, BH-corrected p<0.001), and between the immediate and delayed retention tests (11.5° increase; t(12)=5.262, BH-corrected p<0.001). No significant difference was found between the baseline and delayed retention tests (t(12)= 1.606, BH-corrected p=0.134).

For peak spine flexion velocity, a significant difference was observed between the baseline and immediate retention tests (23.1°/s decrease; t(12)=4.856, BH-corrected p=0.001), between the baseline and delayed retention tests (11.2°/s decrease; t(12)=2.374, BH-corrected p=0.035), and between the immediate and delayed retention tests (11.9°/s increase; t(12)=3.370, BH-corrected p=0.011).

For peak spine extension velocity, a significant difference was observed between the baseline and immediate retention tests (18.9°/s decrease; t(12)=3.749, BH-corrected p=0.007), and between the immediate and delayed retention tests (8.4°/s increase; t(12)=2.531, BH-corrected
4.3.3 Between-group Comparisons

The reductions in peak spine flexion angle that occurred during the time between the baseline and immediate retention tests were significantly different between groups (31.1° decrease in AUG group; 17.1° decrease in DID group; \(t(24)=2.180\), BH-corrected \(p=0.045\)). The reductions in peak spine flexion angle that occurred during the time between the baseline and delayed retention tests were also significantly different between groups (18.7° decrease in AUG group; 5.6° decrease in DID group; \(t(24)=2.301\), BH-corrected \(p=0.041\)).

The reductions in peak spine flexion velocity that occurred during the time between the baseline and immediate retention tests were significantly different between the groups (42.7°/s decrease in AUG group; 23.1°/s decrease in DID group; \(t(24)=2.239\), BH-corrected \(p=0.035\)). The reductions in peak spine flexion velocity that occurred during the time between the baseline and delayed retention tests were also significantly different between the groups (33.3°/s decrease in AUG group; 11.2°/s decrease in DID group; \(t(24)=2.702\), BH-corrected \(p=0.020\)).

The reductions in peak spine extension velocity that occurred during the time between the baseline and immediate retention tests were significantly different between groups (41.8°/s decrease in AUG group; 18.9°/s decrease in DID group; \(t(24)=3.056\), BH-corrected \(p=0.011\)). The reductions in peak spine extension velocity that occurred during the time between the baseline and delayed retention tests were not different between groups (\(t(24)=2.108\), BH-corrected \(p=0.052\)).

4.4 Transfer: Medication Bag Lifting Task

No baseline differences between intervention groups were observed during the bag lifting task for peak spine flexion angle (\(t(24)=0.781\), \(p=0.442\)), peak spine flexion velocity (\(t(24)=0.268\), \(p=0.791\)), or peak spine extension velocity (\(t(24)=1.172\), \(p=0.253\)). No interaction effect was observed for the bag lifting task across any of the three dependent variables (\(p\geq0.082\)), and no main effect of group was observed across any of the three dependent variables (\(p\geq0.795\)). A significant main effect of time was observed for peak spine flexion angle (\(F_{2,48}=30.405\), \(p<0.001\), \(\eta^2_p=0.559\)), peak spine flexion velocity (\(F_{2,48}=19.049\), \(p<0.001\), \(\eta^2_p=0.442\)), and peak spine extension velocity (\(F_{2,48}=41.263\), \(p<0.001\), \(\eta^2_p=0.632\)). The results for both groups are presented in Figure 10. The results of the post-hoc analyses are presented in section 4.4.1.
Figure 10. Results of the kinematic analyses for the bag lifting transfer task: A) Peak spine flexion angle; B) peak spine flexion velocity; C) peak spine extension velocity. The error bars indicate standard error of the mean (SEM). & indicates significant difference between time-points across both groups.
4.4.1 Time Effects across both Intervention Groups

For peak spine flexion angle during the bag lifting task across both intervention groups, a significant difference was observed between the baseline and immediate transfer tests (16.7° decrease; t(25)=7.151, BH-corrected p<0.001), between the baseline and delayed transfer tests (12.1° decrease; t(25)=4.737, BH-corrected p<0.001), and between the immediate and delayed transfer tests (4.5° increase; t(25)=2.944, BH-corrected p=0.007).

For peak spine flexion velocity during the bag lifting task across both intervention groups, a significant difference was observed between the baseline and immediate transfer tests (26.0°/s decrease; t(25)=4.672, BH-corrected p<0.001) and between the baseline and delayed transfer tests (21.23°/s decrease; t(25)=5.455, BH-corrected p<0.001). No significant difference was observed between the immediate and delayed transfer tests (t(25)=1.353, BH-corrected p=0.188).

For peak spine extension velocity during the bag lifting task across both intervention groups, a significant difference was observed between the baseline and immediate transfer tests (23.0°/s decrease; t(25)=8.211, BH-corrected p<0.001), between the baseline and delayed transfer tests (17.1°/s decrease; t(25)=5.448, BH-corrected p<0.001), and between the immediate and delayed transfer tests (5.9°/s increase; t(25)=2.704, BH-corrected p=0.012).

4.5 Transfer: Paramedic Backboard Lifting Task

No baseline differences between intervention groups were observed during the backboard lifting task for peak spine flexion velocity (t(24)=1.561, p=0.132) or peak spine extension velocity (t(24)=1.903, p=0.069). However, a significant baseline difference between intervention groups was observed for peak spine flexion angle (t(24)=2.233, p=0.035). A significant interaction effect was observed for the paramedic backboard lifting task in peak spine flexion velocity (F₂,48=5.157, p=0.009, ηₚ²=0.177) and peak spine extension velocity (F₂,48=4.228, p=0.020, ηₚ²=0.150). No interaction effect nor main effect of group was observed in peak spine flexion angle (p=0.186 and p=0.099, respectively); however, a significant main effect of time was observed (F₂,48=10.385, p<0.001, ηₚ²=0.302). The results for both groups are presented in Figure 11. The results of the post-hoc analyses are presented in sections 4.5.1 to 4.5.4.
Figure 11. Results of the kinematic analyses for the paramedic backboard lifting transfer task: A) Peak spine flexion angle; B) peak spine flexion velocity; C) peak spine extension velocity. The error bars indicate standard error of the mean (SEM). & indicates significant difference between time-points across both groups; * indicates significant difference between time-points in AUG group; # indicates significant difference between time-points in DID group; † indicates significant difference in baseline-to-immediate retention test reduction between groups; ‡ indicates significant difference in baseline-to-delayed transfer test reduction between groups.
4.5.1 Time Effects across both Intervention Groups for Peak Spine Flexion Angle

For peak spine flexion angle during the paramedic backboard task across both intervention groups, a significant difference was observed between the baseline and immediate transfer tests (8.1° decrease; \(t(25)=4.213\), BH-corrected \(p<0.001\)), and between the immediate and delayed transfer tests (6.1° increase; \(t(25)=3.824\), BH-corrected \(p=0.001\)). No significant difference was observed between the baseline and delayed transfer tests (\(t(25)=0.992\), BH-corrected \(p=0.331\)).

4.5.2 AUG Intervention Group

For peak spine flexion velocity in the AUG group, a significant difference was observed between the baseline and immediate transfer tests (23.8°/s decrease; \(t(12)=4.173\), BH-corrected \(p=0.010\)), and between the baseline and delayed transfer tests (15.4°/s decrease; \(t(12)=3.539\), BH-corrected \(p=0.016\)). No significant difference was observed between the immediate and delayed transfer tests (\(t(12)=1.940\), BH-corrected \(p=0.087\)).

For peak spine extension velocity, a significant difference was observed between the baseline and immediate transfer tests (20.6°/s decrease; \(t(12)=4.114\), BH-corrected \(p=0.006\)), and between the immediate and delayed transfer tests (17.5°/s increase; \(t(12)=4.714\), BH-corrected \(p=0.004\)). No significant difference was observed between the baseline and delayed transfer tests (\(t(12)=0.611\), BH-corrected \(p=0.559\)).

4.5.3 DID Intervention Group

For peak spine flexion velocity in the DID group, no significant differences were observed between the baseline and immediate transfer tests (\(t(12)=2.409\), BH-corrected \(p=0.053\)), between the baseline and delayed transfer tests (\(t(12)=0.175\), BH-corrected \(p=0.864\)), and between the immediate and delayed transfer tests (\(t(12)=2.052\), BH-corrected \(p=0.084\)).

For peak spine extension velocity, a significant difference was observed between the immediate and delayed transfer tests (10.5°/s increase; \(t(12)=3.713\), BH-corrected \(p=0.008\)). No significant differences were observed between the baseline and immediate transfer tests (\(t(12)=0.601\), BH-corrected \(p=0.559\)), and between the baseline and delayed transfer tests (\(t(12)=1.670\), BH-corrected \(p=0.169\)).
4.5.4 Between-group Comparisons

The reductions in peak spine flexion velocity that occurred during the time between the baseline and immediate transfer tests were significantly different between groups (23.8°/s decrease in AUG group; 6.8°/s decrease in DID group; \( t(24)=2.673, \) BH-corrected \( p=0.027 \)). The reductions in peak spine flexion velocity that occurred during the time between the baseline and delayed transfer tests were also significantly different between groups (15.4°/s decrease in AUG group; 0.7°/s increase in DID group; \( t(24)=2.762, \) BH-corrected \( p=0.027 \)).

The reductions in peak spine extension velocity that occurred during the time between the baseline and immediate transfer tests were significantly different between groups (20.6°/s decrease in AUG group; 2.7°/s decrease in DID group; \( t(24)=2.642, \) BH-corrected \( p=0.029 \)). The reductions in peak spine extension velocity that occurred during the time between the baseline and delayed transfer tests were not significantly different between groups (\( t(24)=1.581, \) BH-corrected \( p=0.169 \)).
5 Discussion

Paramedics around the world face an elevated risk of sustaining debilitating musculoskeletal injuries, with the majority of them occurring to the low back (Maguire et al., 2005). Although engineering ergonomic controls have been effective in partially reducing injury rates (Armstrong et al., 2017), additional efforts are required to further mitigate injury risk in this population as paramedic work is largely unpredictable and non-modifiable (Coffey et al., 2016). Movement (re)training interventions for paramedic workers represents a crucial component of a comprehensive approach to mitigate injury risk, but effective approaches to still need to be identified (Garcia et al., 2011). The purpose of this study was to determine if a movement (re)training intervention utilizing an augmented feedback (AUG) approach differed from a standard didactic (DID) approach in their ability to elicit acute and one-week sustained retention and transfer of lifting strategies utilizing reduced spine motion during box, medication bag, and paramedic backboard lifting. It was found that an intervention utilizing an AUG approach elicited greater reductions in spine motion during box lifting (i.e., retention) in the immediate and delayed retention tests compared to a DID approach, but was not clearly superior in doing so for the transfer tasks involving paramedic-specific lifts (i.e., medication bag and paramedic backboard lifts). Thorough interpretations of the results with reference to existing literature are presented in the following sections.

5.1 Retention: Box Lifting Task

A box lifting task with a crate was used in the acquisition phase of both interventions as it is a common object, thus easily assessible as a training tool. Participants in both intervention groups were instructed to lift the box using a self-selected technique during the baseline performance tests and did so with an average peak spine flexion angle of 56.2° at average peak spine flexion and extension rates of 74.6°/s and 71.8°/s, respectively. Compared with existing literature that involved similar task parameters and untrained individuals, the baseline performances in this study were very similar to previously-reported findings (e.g., Chan et al., 2017; Burgess-Limerick, Abernethy, Neal, & Kippers, 1995). This similarity in spine kinematic results during lifting with a self-selected technique increases confidence in the measurement methods employed in the current study. Furthermore, these similarities could indicate that the efforts directed at recruiting untrained individuals in this study were indeed successful, assuming the other studies were successful in doing so. As such, lasting improvements were more likely
achievable in the retention task across both intervention groups, as inexperienced individuals have been found to forget less rapidly when it comes to learning a novel task method compared to experienced individuals (Nembhard, 2000).

Both the AUG and DID interventions were generally successful in reducing sagittal plane spine motion observed during the retention (i.e., box lifting) task. Reductions in all dependent variables were observed during the immediate retention test compared to baseline in both intervention groups (i.e., statistically significant acute improvements were detected in both groups). During the delayed retention test performed approximately one-week after the intervention, the DID group showed a significant reduction from baseline in peak spine flexion velocity only, whereas the AUG group again showed reductions from baseline in all dependent variables. It is important to note that although both intervention groups showed improvements from baseline, strictly speaking, no definitive conclusions can be made about either intervention compared to no intervention (i.e., performing 50 practice lifts only and being tested at baseline, immediate, and delayed retention tests), as no control group was included in this study (see sections 3.2.1 and 5.3). In spite of this, there may be several contributing factors for why both interventions were able to elicit an overall positive effect compared to baseline. First, both groups were given the opportunity to practice the task during the intervention. From one theoretical perspective, Bernstein (1967) viewed practice of voluntary goal-directed movements as an opportunity to flexibly employ different movement “solutions” via free(z)ing mechanically redundant degrees of freedom to develop – through self-organizing processes – relatively stable (yet adaptable) functional coordination patterns. From an alternative theoretical perspective, practice of voluntary goal-directed movements can be viewed as an opportunity for error detection and correction via closed-loop control processes (Schmidt & Lee, 2005). Regardless of the perspective used to understand how human movement is coordinated and controlled, it is generally agreed that physical, deliberate practice is essential to elicit learning and acquire a novel skill or technique. Thus, the inclusion of 50 practice lifts with the box in the interventions allowed for an opportunity to “improve” at the skill, despite the fact that the interventions differed significantly in content, structure, and delivery. Furthermore, successful retention likely occurred in both groups as the acquisition phase was performed in very similar conditions to the tests: same lifting parameters; similar fatigue state; and same performance environment (i.e., same testing location, room temperature, lighting, etc.). Thus, substantial changes in the underlying abilities and/or motor coordination patterns were not required in the lifts during the immediate and delayed retention
tests, satisfying the specificity of learning hypothesis (Barnett, Ross, Schmidt, & Todd, 1973). Lastly, it was briefly mentioned in the AUG intervention and elaborated in the DID intervention that excessive spine motion can result in the development and progression of LBD. Although no direct evidence exists to support education used to successfully change untrained individuals’ movement behaviour during lifting, it has been shown in individuals with LBP that education on lumbar spine physiology and self-management can improve their physical capacity and pain reporting (Moseley, 2004; de Jong et al., 2005). Thus, it is feasible that this education may have further encouraged individuals in both intervention groups to modify their lifting strategies.

Despite evidence that both interventions resulted in improvements compared to baseline, the AUG intervention was superior in reducing peak sagittal plane spine motion compared to the DID intervention group at the immediate and delayed retention tests when compared to baseline. It was found that the AUG intervention group made significantly greater immediate reductions in spine motion, and significantly greater longer-term (i.e., one-week) reductions in peak spine flexion angle and velocity. Although the reduction in peak spine extension velocity was not significantly greater in the AUG group compared to the DID group during the delayed retention test, a significant reduction was found between baseline and the delayed retention test in the AUG group whilst this was not found in the DID group (with baseline performances being statistically similar). This between-group difference was expected due to the design of the two interventions. The DID intervention was designed to be a brief version of current movement (re)training interventions, where it is characterized by a lack of individualized feedback and a “blanket-approach” with lecture-style teaching (e.g., Lønn et al., 1999; Garcia et al., 2011; Cecchi et al., 2010). Although it may seem intuitive that verbally teaching how and why to reduce spine motion followed by practice may be effective in improving untrained individuals’ lifting practices, it is generally accepted that this approach to training is ineffective in reducing injury rates amongst workers in a variety of occupations that require manual material or patient handling (Hignett, 2003; Martimo et al., 2008; Daltroy et al., 1997; Garcia et al., 2011). No known work has directly examined the immediate and delayed effects of standard didactic teaching on lifting technique, although several studies have examined the effects of education on pain-reporting and physical capacities in individuals with LBP (Moseley, 2004; de Jong et al., 2005) and a nursing population (Warming et al., 2008). The results of the current study suggest that didactic approaches combined with practice has the potential to change lifting technique (at least compared to baseline in untrained individuals), but it may not be as effective as an augmented feedback approach without
any didactic teaching or lecture. The AUG intervention incorporated position-control-based guidance, individualized coaching cues, and self-controlled, faded-frequency knowledge of performance (KP) feedback. On their own, these forms and methods of administering augmented feedback have been found to be effective for various purposes. For example, position-control-based guidance has been found to be effective for acutely reducing spine motion during lifting in untrained individuals (Carnegie et al., 2016), in rehabilitation settings for the (re)training of walking and upper-limb movements (Marchal-Crespo & Reinkensmeyer, 2009), and in a sport context for the learning of skiing (Wulf, Shea, & Whitacre, 1998), amongst other uses. Knowledge of performance feedback has been shown to facilitate learning of soccer throw-ins (Weeks & Kordus, 1998), coincident timing tasks (Young & Schmidt, 1992), volleyball serves (Zubiaur et al., 1999), and is commonly provided to students by coaches/instructors to convey kinematic information that is not readily available to the learner (Schmidt & Lee, 2005). Considering the research regarding the two contrasting approaches used in this study, it is perhaps not surprising that individuals in the AUG intervention exhibited larger reductions in spine motion compared to those in the DID intervention.

Individuals in the AUG intervention group exhibited an immediate reduction in peak spine flexion angle of 31.1°, and a reduction of 18.7° one-week later. This constituted a 51.3% and 31.8% decrease from baseline, respectively. These large changes could be practically significant, as peak spine flexion angle has been found to be a LBD risk factor (Marras et al., 1995; Punnett et al., 1991), and relatively small changes in spinal posture can significantly influence both cumulative (e.g., Holmes, Hodder, & Keir, 2010) and peak low back loading (Adams et al., 1994). This occurs because the alignment and curvature of the spinal column affects its ability to safely support and transmit mechanical loads by altering the functional load-sharing amongst active and passive tissues (McGill, 2004). Individuals in the DID intervention group showed an immediate 17.1° reduction in peak spine flexion angle, thus constituting a 33.0% decrease from baseline. However, these immediate retention effects were not sustained, as no significant change from baseline was observed one-week later in the DID group. Support for using both intervention approaches was offered based on the large decreases in peak spine flexion and extension velocities following training. The baseline peak flexion and extension velocities in the both intervention groups, which were not statistically different at baseline, were considered to be in the high-risk category (i.e., greater than 59°/s) according to the normative categories developed by Marras et al. (1995). However, immediately after the AUG intervention, participants’ peak spine flexion and
extension velocities were in the low-risk category (i.e., less than 53.7°/s; Marras et al., 1995), and remained in this category when they returned one-week later. Individuals in the DID intervention group immediately improved to medium-risk category and remained here when they returned one-week later. Thus, from an injury prevention standpoint, desirable improvements occurred in the retention task in both AUG and DID intervention groups, with larger and perhaps more practically-relevant improvements occurring in the AUG intervention group.

5.2 Transfer: Medication Bag and Paramedic Backboard Lifting Tasks

The medication bag and paramedic backboard lifts were selected as the transfer tasks for this study because the physical appearance, mass, starting height, and coupling differed markedly from the box lifting retention task. Furthermore, the medication bag lift was an asymmetrical task, whereas the backboard lift was a concurrent joint action task where coordination was required between two individuals. Participants in both intervention groups were instructed to lift the objects using a self-selected technique during the baseline performance tests. In the medication bag lifting task at baseline, the average peak spine flexion angle, flexion velocity, and extension velocity across both groups were 49.4°, 70.4°/s, and 63.2°/s, respectively. Although no known studies have presented postural (i.e., kinematic) analyses on the medication bag lift specifically, Allread, Marras, & Parnianpour (1996) have shown that individuals performing one-handed lifts of a 10.2kg box with a self-selected technique lifted with average peak trunk flexion angles of 30.9°, at rates of 55.1°/s. These discrepancies may be explained by differences in measurements devices, differences in dependent variables (i.e., spine versus trunk flexion), and differences in initial position of the object lifted; individuals in Allread et al. (1996) lifted from 76cm off the ground, whereas individuals in this study grasped a handle that began 26cm off the ground and extended to 41cm off the ground at the moment the bag elevated off the ground. This discrepancy is less likely to be explained by the 1.5kg difference in mass, as non-significant differences were observed in sagittal-plane trunk motion when the box masses were 3.4kg and 6.8kg lighter (than the 10.2kg box) in the study by Allread et al. (1996). In the paramedic backboard lifting task in this study, individuals in both groups lifted with an average peak spine flexion angle of 68.6° at rates of 73.0°/s for flexion and 76.6°/s for extension when asked to perform with a self-selected technique at baseline. This result was similar to that found amongst experienced paramedics, where the average peak spine flexion angle during this task was found to be 70° (Lavender et al., 2000b).
This similar result suggests that minimal differences in spine motion exist during the performance of this task between individuals with and without experience as a paramedic. This is in-line with previous literature that suggests there are little differences in spine kinematics and kinetics between workers with and without experience when performing occupational lifts (e.g., Lee & Nussbaum, 2012; Marras et al., 2006).

Biomechanical analyses on the performance of the medication bag lift have not been reported but was selected for this study as a transfer task because it is one of the commonly-performed tasks that has been rated by paramedics as being physically demanding (Coffey et al., 2016; Prairie & Corbeil, 2014). Across both intervention groups, participants exhibited immediate improvements in all spine kinematic variables compared baseline, and significant improvements remained during the delayed transfer test one-week later. Again, it must be noted that no conclusions can be made about the influence of the interventions compared to lifting practice only, as no control group was included in this study. For peak spine flexion angle, individuals showed a 33.8% decrease from baseline immediately post-intervention, and a 24.6% decrease from baseline remained one-week later. If these relatively large changes could be elicited in paramedics, cumulative spine loading, and subsequently LBD risk, may be mitigated because paramedics lift and carry medication bags to nearly every call (Coffey et al., 2016). For the peak spine flexion and extension velocities, both groups lifted at baseline with velocities that placed them in the high-risk category (i.e., greater than 59°/s; Marras et al., 1995), but their improvements at both the immediate and delayed transfer tests placed them low-risk category (i.e., less than 53.7°/s; Marras et al., 1995). Thus, it appears as though undergoing either the AUG or DID training approaches may be effective in mitigating LBD risk associated with frequently handling the medication bag; however, no differences in improvements existed between the two intervention groups.

It was hypothesized that the AUG intervention would elicit greater improvements compared to the DID intervention during transfer testing, but this was not the case with the medication bag lift. One potential reason for this is the fact that this was a one-handed lifting task, constituting an asymmetrical external load that forces individuals to not only resist spine flexion, but also spine lateral bending and/or axial twisting (Allread et al., 1996). The DID group received specific instruction during the presentation to avoid twisting at the spine because it places greater stress on the spinal structures during lifting (based off OHCOW Guidelines for the Prevention of Back Injuries in Paramedics, Module 2: Preventing Injuries; slideshow presentation in Appendix E). This group was instructed to pivot at the feet before initiating lifts, while the AUG intervention
group was not trained or educated about how to approach asymmetrical or one-handed lifting tasks. No data were collected on how individuals chose to perform the medication bag lift (i.e., if they staggered their feet, or “squared up” to the bag prior to the lift), but the DID group may have been more inclined to position themselves to face the bag by pivoting at their feet before the lift due to the additional education. Furthermore, kinematics in the transverse and coronal planes were not quantified in this study, which may have differed between groups if the DID group was truly more inclined to position their body facing the load before the lifts. While didactic education has yet to be supported by empirical evidence to be efficacious in altering movement mechanics, the AUG intervention lacked any specific education, instruction, or feedback regarding asymmetrical/one-handed lifts or pertaining to lateral bending or axial twisting of the spine. Thus, despite the use of various forms of augmented feedback and individualized coaching cues in the AUG intervention (which was lacking in the DID intervention), it is understandable that the two interventions did not differ in their effectiveness for this task. If augmented feedback approaches are to be implemented in the future, it may be beneficial to include ancillary instruction regarding asymmetrical lifting tasks, and/or provide exposure to such tasks during the acquisition phase (i.e., physical practice); otherwise, didactic education may be equally (in)effective.

The paramedic backboard lift was selected as another transfer task in this study because it is commonly-performed amongst paramedics, with services performing this task up to an average of six times per shift (Ontario-North service; Coffey et al., 2016). Furthermore, this task inherently places workers in extreme postures due to the low initial height (Lavender et al., 2000b), thus subjecting them to spinal compression loads that exceed the NIOSH-recommended action limit (AL) of 3400N (Lavender et al., 2000a; NIOSH, 1981). Potentially attributable (in-part) to the low initial height of the backboard handles (0.03m), neither interventions were capable of eliciting lasting changes in participants’ peak spine flexion position. Across both intervention groups, participants showed a significant immediate reduction in peak spine flexion angle of 11.8%, but no change from baseline remained after one-week. This immediate minor improvement may be practically significant from an injury prevention standpoint because as the spine approaches its end-range of flexion motion, a greater proportion of the mechanical loads that must be supported by the spine column are transferred to tissues with lower and less adaptable tolerance (Beach, Parkinson, Stothart, & Callaghan, 2005). However, other intervention approaches warrant consideration (e.g., equipment changes or combined approaches) to further mitigate risk for this task as no changes lasted after one-week. Thus, it can be interpreted that an AUG or DID approach
has the potential to elicit transfer of learning to limit extreme spine flexion when executing a novel lifting task, but additional practice and/or exposure to lifts with similar loads and initial heights may be required to ensure that the acquired lifting strategies are maintained in the longer-term. For peak spine flexion velocity, the AUG group exhibited 29.8% and 19.3% reductions during the immediate and delayed transfer tests, respectively. For peak spine extension velocity, the AUG group exhibited a 24.4% reduction from baseline in the immediate transfer test, but no changes remained after one-week. Although relatively large changes in velocities were observed in the AUG intervention group representing a reduction in LBD risk, their performance remained in the high-risk category according to Marras et al., (1995) at all time points. The DID group showed no changes from baseline during either post-intervention transfer tests in peak spine flexion and extension velocities, suggesting that a didactic approach to movement (re)training may be ineffective for reducing the rate of spine flexion/extension motion used during this task.

It was hypothesized that the AUG intervention would elicit different spine kinematic changes compared to the DID intervention during transfer testing, but this was only partially supported by the results of the paramedic backboard lifting task. Specifically, the effects of the two interventions differed for peak spine flexion and extension velocities, but not for peak spine flexion angle. Differences were observed in baseline performance for this dependent variable, but this was not rectified as no main effect of group was observed overall. One factor that may partially explain the small magnitude immediate improvement in peak spine flexion position that failed to remain after one-week is that this was a relatively heavy lift. With a mean participant mass in this study of 69.6kg, participants lifted an average of 59.3% of their body mass, ranging from 36.4 to 82.0% of their body mass. This load lifted three times consecutively may be very difficult for an untrained individual, to the point where some individuals were likely to have limitations in their back extensor strength – biomechanical analyses conducted by Lavender et al., (2000a) found that when performing backboard lifts of 540N, approximately 8% of the average population would lack the requisite strength to perform the task. This percentage would be higher for the backboard lift in the current study as the backboard and mannequin combined to weigh 809.3N. Furthermore, it has been found that when lifts are heavy relative to an individuals’ capacity, they may perform the lift at near full spine flexion (Cholewicki & McGill, 1992), which was what was observed in this study. This heavy lift is compounded by the low initial handle height of 3cm, which may oblige individuals to utilize a greater proportion of their available spine flexion range-of-motion. Research consistently demonstrates that the lower the initial height of the lift, the greater the
muscular load, peak spine flexion angle, peak low back moments, peak compressive forces, and peak anterior-posterior forces (Nielsen et al., 1998; Lavender et al., 2003; 2000a; Hoozemans et al., 2008; Straker, 1999; Noone & Maxumdar, 1992; see section 2.2.2). In fact, Lavender et al. (2003) were able to show that 72% of the total variance in peak L5/S1 moment could be explained by lifting height, load magnitude, and lifting speed. The minor effect of the two interventions, as well as the lack of difference between the effects of the two interventions on peak spine flexion angle in the backboard lift may be explained by the fact that untrained individuals may lack the physical capacity (e.g., physical strength, range-of-motion in the lower extremity joints) to perform the low-lying, relatively heavy lift without flexing the spine (Noone & Maxumdar, 1992). Thus, there may have not been much room for improvement to begin with. This suggests that engineering ergonomic changes to the paramedic backboard are warranted, specifically changes that can increase the initial handle height (e.g., handles that curve up to raise the handle height). Differences between intervention groups did exist for peak spine flexion velocity, where the AUG group significantly reduced their peak flexion velocity and maintained this improvement one-week later (with no between-group differences in duty cycle). A reduction in peak spine flexion velocity not accompanied by a reduction in peak spine flexion angle during the delayed transfer test demonstrates that the AUG group moved through the same spine flexion range-of-motion throughout the post-intervention lifts as the pre-intervention lifts, but did so in a “smoother” fashion. This could indicate that these individuals may have deliberately attempted to limit spine flexion as intended in the AUG intervention (i.e., had the requisite coordination to maintain the movement feature), but were not physically capable of doing so throughout the entire lift due to deficits in strength and/or range-of-motion capacities (to adapt to the mass and/or low initial height). The lack of change from baseline in the DID group suggests that didactic teaching approaches may be inadequate to elicit transfer of learning to tasks that are difficult to safely perform.

5.3 Practical Application

The results of this study support the use of an augmented feedback approach over a traditional didactic approach to injury prevention movement (re)training. However, practical implementation of the AUG approach in a workplace training environment present additional and different considerations compared to using this approach in a controlled, laboratory setting. Perhaps the most important consideration is that workplace training environments are unlikely to
have access to a motion capture system (or other real-time spine flexion measurement devices) due to their specific uses, requirement of a technician, and the high cost of equipment. This means that the source of the KP regarding the peak spine flexion angle reached during lifting practice must be provided via coaches’ visual observation. Because spine posture has been shown to be difficult to assess solely using visual observation (e.g., Fedorak, Ashworth, Marshall, & Paull, 2003), it is recommended that coaches be trained in order to be proficient at accurately observing and reporting spine flexion angles to workers.

Movement (re)training for paramedics with an AUG approach should also be provided over more and/or longer training sessions that involve various tasks and exercises, such as those that will be performed on the job. The results of this study suggest that learning may have occurred after one brief session involving one practice task, but additional training (i.e., acquisition) sessions that occur over the course of several days to weeks would further ensure learning occurs successfully in workers (e.g., Young & Schmidt, 1992; Beach et al., 2014; Frost et al., 2015a). This is especially recommended because the transfer effects observed in this study were less pronounced than that of the retention effects. It is also suggested that this training be provided in conjunction with an exercise program aimed to increase workers’ physical fitness to form a comprehensive risk mitigation strategy, as previous work has demonstrated that an exercise program designed with a focus on improving movement coordination (as well as physical fitness) can reduce musculoskeletal loading and associated risk for injury in sport (e.g., Myer et al., 2007; Greska et al., 2012) and firefighting contexts (e.g., Cady, Thomas, & Karwasky, 1985; Beach et al., 2014). The addition of an exercise component will also allow many workers to participate in the program concurrently, whilst coaches can only train several workers using the AUG approach at any given time. Furthermore, this setup allows for a greater coach-to-worker ratio, thus increasing its cost-effectiveness – an important consideration because this method may be inherently more costly in the short-term compared to a traditional didactic approach.

Traditional approaches to movement (re)training centered around teaching theoretical concepts is likely more cost-efficient than an AUG approach in the short-term due to the necessity of very few instructors, and in some instances, using only videos and/or documentation (e.g., OHCOW Guidelines for the Prevention of Back Injuries in Paramedics). However, the results of this study have demonstrated that this didactic approach has less potential to influence learning of spine sparing lifting techniques compared to an AUG approach, and has been demonstrated to be ineffective in influencing injury rates in on the job (e.g., Hignett, 2003; Garcia et al., 2011). Thus,
if cost-effectiveness is an important consideration for paramedic services looking to reduce injury rates and associated worker compensation costs, then it is argued that the larger immediate costs that accompany an augmented feedback movement (re)training intervention will be overshadowed by the potential long-term reduction in worker compensation costs. Although it has not been proven in practice yet, the practical application of an AUG approach shows promise for not only viably reducing paramedic injury rates, but also being cost-effective in the long-term.

5.4 Limitations

The study findings were interpreted with careful consideration of three major limitations in the experimental design, the first of which is that no control group was implemented in this study. This choice was made because the comparison between a novel and traditional approach to movement (re)training was the primary purpose of the study, instead of establishing the efficacy of either approach individually. The specific effects of performing 50 box lifts and the box, medication bag, and paramedic backboard lifts before and twice after the 50 box lifts (without intervention) have not been quantified. As such, it cannot be discounted that simply practicing lifting in a training setting contributed to the results obtained. However, existing evidence does not support the fact that untrained individuals would reduce spine flexion displacements by approximately 51.3% and flexion/extension velocities by 53.7% (observed acutely in the AUG group in the current study) due to practice/familiarization only. Studies that have quantified the variability in spine kinematics in response to repetitive lifting have shown that changes that occur are typically far smaller than what has been observed in the current study (e.g., 7.1% increase in peak spine flexion after 100 lifts in Dolan & Adams, 1998; increase in peak lumbosacral flexion angle during 40 minutes of barbell lifting in van Dieën, van der Burg, Raaijmakers, & Toussaint, 1998). Additionally, Frost et al. (2015a) contrasted movement (re)training approaches for firefighters and found that those who were in either the 12-week physical fitness training intervention group or the control group (i.e., who continued their regular training regimens) showed no post-intervention changes in spine kinematics during box lifting. Thus, the general finding that there were differential effects of AUG and DID interventions suggests, at the very least, that the AUG training would likely perform better than practicing alone. Finally, all interpretations of the effects of both groups are in relation to the participants’ performance at baseline, and the effects of both groups in relation to each other.
The controlled, biomechanics laboratory setting is another limitation that must be considered when interpreting these findings. The environmental and situational context under which this study was conducted is not ecologically valid compared to the true conditions under which paramedics perform these tasks. Paramedic work occurs in vast variety of settings, ranging from patients’ homes, parks, schools, streets, etc., making a “typical” call environment very difficult to describe or recreate (Tangherlini, 1998). Furthermore, paramedic work involves intense psychological stressors combined with a large cognitive load, as the life or death of a patient can depend on the performance of their job (Regehr & Millar, 2007). These factors have the potential to significantly influence lifting techniques. For example, it has been demonstrated that during urgent calls, where an immediate threat to life or limb is present, paramedics perform tasks with significantly greater trunk motion (and therefore greater LBD risk) compared to non-urgent calls (Prairie & Corbeil, 2014). The time pressure is not only a psychological stressor, but also a factor that can act as a constraint on the number of movement solutions available to paramedics, which is not a factor in the current study. Another example of how differences in environment may influence lifting techniques is the fact that paramedics often work in tight spaces that force them into awkward postures (e.g., Coffey et al., 2016), thus further limiting available movement solutions to perform a given task. It has been shown that paramedics resort to different techniques to lift and carry a backboard when they are required to descend staircases with and without corners (Lavender et al., 2000a; 2000b), whereas all individuals had ample space to perform this lift in the laboratory environment. Considering this limitation, the results of this study can only be used to understand how the studied movement (re)training approaches compare in changing inexperienced individuals’ movement behaviour from baseline in an ideal setting, and cannot be extrapolated to represent how they may perform on-the-job. Additional training will likely be required before workers can stabilize these key movement features to the point where the features can be maintained during emergency situations without explicit conscious focus (i.e., becomes a habit).

The third limitation that must be considered is that participants in this study were exposed to the transfer task prior to the acquisition phase and transfer tests. This was kept in the experimental design because a lack of a control group meant that any changes in transfer task performance due to the interventions could not be determined by comparing to a control groups’ performance, but instead could only be quantified in comparison to individuals’ own baseline performance. Traditionally, transfer has been defined as “the ability to apply a particular skill, or bit of knowledge, to situations differing from those encountered during original learning” (Royer,
Although the acquisition phase (i.e., the interventions) is when the original learning occurred in the context of this study, learners are likely to have benefitted from the baseline tasks as part of the original learning because the lifting tasks all preceded the post-intervention tests. In other words, the artificial “separation” of the baseline tests and the intervention likely did nothing to change the fact that individuals had recent exposure to both transfer tasks. As such, studies in motor learning literature do not regularly expose participants to the transfer task(s) until after the acquisition phase. Thus, for this study, it may seem reasonable to expect that participants’ improvements on the transfer tasks during the immediate and delayed tests in both groups may be slightly greater than what would be expected if they had never performed the medication bag and paramedic backboard lift before. However, this effect may be attenuated by the fact that both transfer tasks constitute far transfers, where the stimulus complex for the acquisition task are not similar to those of the transfer tasks; specifically, the physical appearance, mass, starting height, and coupling of the medication bag and backboard lifting tasks differ from the box lifting task (Royer, 1979; Mayer, 1975). Transfer of learning effects in far transfers are typically less pronounced than those observed in near transfers (Royer, 1979; Mayer, 1975). Therefore, it may also be possible that three repetitions of each transfer task were far too few repetitions for participants to have become familiar with them. As the contributions of these factors to the post-intervention results cannot be quantified, the results must be interpreted with the cognizance that some uncertainty lies in how much (if at all) a brief, premature exposure to the transfer tasks may have affected the results.

5.5 Future Directions for Research

The findings of this study raise additional opportunities for research to determine how to best approach movement (re)training. First, it would be valuable to determine the efficacy of an augmented feedback intervention approach by comparing it to no training in randomized controlled trials. This would reveal the potential (or lack thereof) of this approach to mitigate injury risk in paramedics or other populations (e.g., firefighters, nurses, manual laborers, athletes, etc.). Another important question that follows from this work is to determine if AUG and DID approaches in combination (i.e., utilizing multimodal augmented feedback, individualized coaching cues, and education) are more effective than using an AUG approach alone. This combined approach could be beneficial as a didactic approach may have benefits in educating workers about tasks that cannot be readily practiced. Additionally, although random practice was
not implemented in this study, it has been found to facilitate motor learning of novel skills and techniques (Schmidt & Lee, 2005). Future research implementing random practice would be helpful in determining if randomized training is superior to no randomization during the learning of the hip-hinge movement pattern. Another important consideration is that KP feedback was provided in the current study via the use of an optoelectronic motion capture system, with real-time feedback calculated in Visual 3D software – it is unlikely that this expensive technology would be accessible to workplaces looking to implement this approach to movement (re)training. Thus, if an AUG approach is to be used, workplaces would need to rely on other technology (e.g., a CUELA system used by Prairie & Corbeil, 2014) and/or coaches’ visual observation to determine the qualitative KP feedback to provide. Future research should be directed at determining the sensitivity of trained coaches’ ability to visually detect changes in spine posture during lifting tasks (to our knowledge, this has only been studied in upright standing; Fedorak et al., 2003), and to determine if the efficacy of this approach with the human visual observation is similar to that of a motion capture system (i.e., does the reduction in accuracy and/or sensitivity in using visual observation appreciably reduce the effectiveness of this intervention approach). Lastly, using prospective research studies, it would be important to determine if an augmented feedback intervention approach is effective in reducing injury risk in practice. Improvements have been found to last for at least one-week after a brief intervention in this study, but more work is required to determine how long these changes remain and if they can successfully transfer to the workplace to ultimately reduce injury risk.

5.6 Conclusion

Musculoskeletal injuries are extremely common amongst paramedics around the world (Maguire et al., 2005; Aasa et al., 2005). Advancements in engineering ergonomic controls have reduced injury risk substantially, but the injury rates remain high (Armstrong et al., 2017). Movement (re)training interventions may be a necessary component of a comprehensive strategy to mitigate LBD risk amongst paramedics, and therefore must supplement equipment provisions due to the non-modifiable nature of many tasks (Fisher & Wintermeyer, 2012; Coffey et al., 2016; Makhoul et al., 2016), as well as the propensity for workers to attenuate the intended effects of ergonomic interventions by altering lifting behaviours (Faber, Kingma, & van Dieën, 2007). However, interventions based on technique training have not been supported in the literature, but a critical appraisal of existing training approaches suggests that they still be warranted (Hignett,
2003; Garcia et al., 2011; Daltroy et al., 1997). A movement (re)training approach with structured practice and multimodal augmented feedback (AUG) was created and compared to a standard didactic approach (DID) in untrained individuals. The purpose of this study was to determine if movement (re)training utilizing the AUG approach differed from a DID approach in their ability to elicit immediate and one-week delayed reductions in spine motion during retention and transfer testing with paramedic lifting tasks. The results of this study show that the AUG approach is superior to the DID approach in reducing spine motion during a retention task in untrained individuals, but it is not clearly superior for the transfer of learning to paramedic-specific lifting tasks. The results of this study may be used to inform and/or justify augmented feedback schedules for movement (re)training interventions in other occupations, as well as feedback schedules for new wearable technology that are used to improve lifting behaviour amongst nurses, personal support workers, manual material handlers, etc. (e.g., Posture Coach; Doss et al., 2018). In conclusion, the findings support the movement (re)training interventions with an augmented feedback approach over a standard didactic approach to elicit lasting changes in the lifting techniques of untrained workers in tasks that are practiced, but more training may be needed to ensure generalizability of training to unrehearsed lifting tasks.
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Appendices

Appendix A. Physical Activity Readiness Questionnaire (PAR-Q)

**PAR-Q & YOU**

*(A Questionnaire for People Aged 15 to 69)*

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

<table>
<thead>
<tr>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Have your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?</td>
<td></td>
</tr>
<tr>
<td>2. Do you feel pain in your chest when you do physical activity?</td>
<td></td>
</tr>
<tr>
<td>3. In the past month, have you had chest pain when you were not doing physical activity?</td>
<td></td>
</tr>
<tr>
<td>4. Do you lose your balance because of dizziness or do you ever lose consciousness?</td>
<td></td>
</tr>
<tr>
<td>5. Do you have a bone or joint problem (for example, back, knee, or hip) that could be made worse by a change in your physical activity?</td>
<td></td>
</tr>
<tr>
<td>6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?</td>
<td></td>
</tr>
<tr>
<td>7. Do you know of any other reason why you should not do physical activity?</td>
<td></td>
</tr>
</tbody>
</table>

**If you answered YES to one or more questions**

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES. You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.

Find out which community programs are safe and helpful for you.

**NO to all questions**

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active — begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal — this is an excellent way to determine your basic fitness so that you can plan the best way for you to live activity. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 140/84, tell your doctor before you start becoming much more physically active.

**Information about the PAR-Q**: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

**No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.**

**Note**: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

“I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction.”

**NAME**: 

**SIGNATURE OF PARENT or GUARDIAN (if participant is under the age of majority)**

**DATE**: 

**WITNESS**: 

**Note**: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

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Appendix B. Recruitment poster

UNIVERSITY OF TORONTO  
FACULTY OF KINESIOLOGY & PHYSICAL EDUCATION  

PARTICIPANTS NEEDED!
For a biomechanical study investigating the effectiveness of a brief training program to improve lifting technique for the performance of paramedic-specific lifting tasks

For your participation, you will receive formal lifting training, $30, and be entered in a draw to win an Apple iPad Mini! (approx. 1 in 24 chance)

Participants are asked to:
- Attend 2 laboratory sessions one week apart; 90 and 30 minutes in duration
- Participate in a brief 1-on-1 lifting training program during the 1st session
- Perform box, medication bag, and dummy backboard lifts (6, 8.7, and 41 kg lifts)
- Wear motion capture markers over compression clothing to measure spine motion

Eligible participants must:
- Be male or female aged 19-29 years
- Be pain & injury-free, and cleared to participate in physical activity
- Have no current or previous experience working as a paramedic
- Have no experience in Olympic or power lifting, nor formally taught to lift in a strength & conditioning program
- Have not participated in a manual material or patient handling safety program

If you are interested in learning more about the study, please contact:
Appendix C. Information and Consent Form

Information and Consent Form

Study Title

Chan, Frost, Welsh, Trembley, & Beech. Comparing augmented feedback and didactic approaches to change lifting technique during paramedic-specific tasks: A laboratory-based motor learning study

Background and Study Purpose

Lifting training programs are recommended for workers who lift equipment, tools, and/or patients on-the-job to reduce low-back injury risk. However, there are currently no such programs offered for paramedics, who frequently hurt their lower backs. Thus, the purpose of this study is to determine the short- and long-term effects of different lifting (re)training interventions on low-back motions.

Testing Procedures

As a participant in this study, you will undergo a 90-minute laboratory testing and intervention session, followed by a 30-minute testing session one-week later. During the first session, you will undergo baseline performance testing consisting of three of each of the following lifts: box lifts (6kg); medication bag lifts (8.7kg); and lifts of a dummy on a paramedic backboard (52kg, half is lifted by a research assistant). This will be followed by a brief, training intervention, where you will perform a practical component consisting of five sets of ten box lifts. After, the immediate effects of the intervention will be tested by undergoing the same performance tests at baseline. The second session aims to determine how much you have retained from the intervention; thus, you will perform the performance tests again. Throughout the study, you will receive enough rest between lifting tasks to ensure you do not fatigue. The motion of your spine will be recorded using motion capture technology. Rigid bodies with reflective markers will be worn over compression shirt and shorts (i.e., tight-fitting shirt and shorts). This is required for precise measurement of spine motion. Your back length will be measured for the accurate fitting of the rigid bodies, and this requires the researcher to palpate your back and use a washable marker to landmark the L5 and T12 vertebrae.

Risks and Benefits

The lifts you will be asked to perform are considered low-risk for pain- and injury-free populations. However, it is possible that you will experience very minor muscular discomfort or strains from performing the tasks. Some participants may experience minimal skin irritation from donning the rigid bodies, which are comparable to wearing climbing harnesses. There are no direct benefits to you as a participant; however, you will receive an opportunity to learn to perform lifting tasks in a manner that reduces your risk for low-back injuries and an educational opportunity to observe your low-back motion data for your participation. The results of this research will also benefit occupational health and safety specialists who are working to reduce the injury rates associated with working in the paramedic occupation. However, your decision to not participate and/or withdraw will not have a positive or negative effect on your standing in any of your courses at the University of Toronto, and you can do so any time before or during the study.

Confidentiality and Privacy of Information

If you agree to participate, a unique alphanumeric identification code will be assigned to you. Your motion data will be linked with this code, and your personal information will only be linked with the alphanumeric code in a confidential file. Only the faculty supervisor will have access to this file and will keep this information
locked in his personal filing cabinet until the end of the study period. All de-personalized data will be encrypted and stored on password-protected storage drives that are locked up in the Musculoskeletal Biomechanics and Injury Prevention Laboratory (Clara Benson Building, Room 059) indefinitely. This data may be used in further analyses beyond this study.

Participation & Withdrawing consent

You are eligible to participate if you are aged 19-29 years, pain-free, have no musculoskeletal injuries in the past 12-months, and cleared to participate in physical activity. You must also have no experience working as a paramedic, have no patient or manual handling lifting training, and no advanced weight lifting experience. As a participant in this study, you have the right to withdraw your consent at any time before and during the study (including the time between the two sessions) without penalty. If you decide not to participate in any tasks during data collection, you will not be allowed to continue the study, and therefore will constitute as a withdraw from the study. To do so, indicate this to the investigators by saying: "I no longer wish to participate in this study" or something similar. All data collected from you will be deleted after this request. Your participation is voluntary, and there will not be a positive or negative effect on your standing in any of your courses at the University of Toronto.

Compensation

For your participation in this study, there will be financial compensation provided to you, as well as a draw entry to win an Apple iPad Mini. Specifically, $15 will be provided at the end of the first testing session (day 1), and an additional $15 will be provided at the end of the second testing session (day 2); divided in this manner to encourage complete participation. If you withdraw from the study before the first collection, you will not receive any compensation. If you withdraw during or after the first collection before the second collection, you will keep only the first installment of $15. If you withdraw during the second collection, you will keep both instalments of $15, but not be entered in the draw for the iPad Mini. You are entered in the draw if you complete both sessions without withdrawing from the study.

Inquiries

If you have any further questions or would like to receive more information about this study, please contact the principal investigator (Victor Chan) or his supervisor (Dr. Tyson Beach). If you have questions about your rights as a research participant, please contact the Office of Research Ethics.

Victor Chan, MSc Researcher  
Department of Exercise Sciences  
University of Toronto

Dr. Tyson Beach, Assistant Professor  
Department of Exercise Sciences  
University of Toronto

Office of Research Ethics  
University of Toronto  
McMurrich Building, 2nd Floor
Consent to Participate

By signing below, I confirm that:

- I have read this information form and understand the potential risks and benefits associated with participation in this study, and
- I have had the opportunity to ask questions about this study and received satisfactory answers to my questions, and
- I am aware that I can withdraw from the study without adverse consequences at any time by advising the investigators of this decision, and
- I agree to participate in this study: Comparing augmented feedback and didactic approaches to change lifting technique during paramedic-specific tasks: A laboratory-based motor learning study

<table>
<thead>
<tr>
<th>Participant Name</th>
<th>Participant Signature</th>
<th>Date</th>
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<tbody>
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<td></td>
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<table>
<thead>
<tr>
<th>Witness Name</th>
<th>Witness Signature</th>
<th>Date</th>
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</thead>
<tbody>
<tr>
<td>(Please Print)</td>
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</tr>
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</table>
Appendix D. Borg’s CR-10 RPE scale (adapted from Borg, 1990)

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Nothing at all</td>
</tr>
<tr>
<td>0.5</td>
<td>Extremely weak (just noticeable)</td>
</tr>
<tr>
<td>1</td>
<td>Very weak</td>
</tr>
<tr>
<td>2</td>
<td>Weak (light)</td>
</tr>
<tr>
<td>3</td>
<td>Moderate</td>
</tr>
<tr>
<td>4</td>
<td>Strong (heavy)</td>
</tr>
<tr>
<td>5</td>
<td>Very strong</td>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Extremely strong (almost max)</td>
</tr>
<tr>
<td>•</td>
<td>Maximal</td>
</tr>
</tbody>
</table>
GUIDELINES FOR THE PREVENTION OF BACK INJURIES IN PARAMEDICS

PURPOSE, GOALS, AND OBJECTIVES

- To educate and provide safe lifting guidelines, to reduce back injury through preventative measures
WHAT DOES THE RESEARCH SAY?

- The most common injuries to Paramedics are sprains to the low back largely due to:
  - Lifting and twisting
  - Bending and lifting
  - Pulling

- Paramedics showed the highest rate of Early Retirement on Medical Grounds: 55/1000 employees per year

Once you have suffered a back injury, your chance of re-injury is 3-5 times greater.

SITUATIONS WHERE INJURIES CAN OCCUR
# SITUATIONS WHERE INJURIES CAN OCCUR

- Heavy lifting with awkward postures
- Kneeling, crouching, awkward sitting
- Prolonged sitting

# TYPES OF INJURIES

## ACUTE:
- Single incidence
- Usually involving a painful muscle strain and/or ligament sprain from a slip, trip, fall, or an improper lift

## CUMULATIVE:
- Micro-damage to the body’s structures (ex. The back) over time
- Since the micro-damage is not very painful, the damage is not noticed until it starts to become disabling

## CHRONIC:
- Ongoing radiating pain for more than 6 weeks
- Can result from acute or cumulative trauma either alone or in combination
FACTORS THAT CONTRIBUTE TO INJURY

- Body weight
- Improper lifting techniques
- Previous injury
- Genetics

ACUTE

CUMULATIVE

CHRONIC

Areas at risk of injury include:

- Muscles
- Ligaments
- Intervertebral disks
- Vertebrae
- Nerves
The Anatomy of the Spine and How the Spine Works

- Composed of bones, discs, nerves, muscles and ligaments
- When an injury occurs, one or more of these structures are damaged and the spine is unable to function properly
INTERVERTEBRAL DISCS

- Separates vertebrae and acts as a shock absorber
- Degeneration can occur with chronic compressive forces or a single acute injury
- Becomes less elastic with degeneration and can rupture, bulging outwards towards the spinal cord.

THE SPINAL CORD

- Protected by and runs down the vertebrae
- Controls muscles and Organs
- Pressure on the spinal cord can lead to great discomfort and pain, or even paralysis
SUPPORTING MUSCLES

BACK
Provision stabilization and movement
Keep vertebrae aligned

STOMACH
Stabilize the spine and protect the lower back.
Strong core muscles can help prevent the risk of injury.

All of these muscles can be injured during an improper lift or with an excessive load.

ERGONOMICS
ERGONOMICS

A person’s efficiency to produce physical work

- **Ergonomic Risk Factors**
  - **Force**
    - Compression
    - Tension
    - Shear
    - Torsion
    - Vibration
  - **Posture**
    - Awkward postures while lifting/carrying
      - Bending
      - Twisting
      - Reaching
  - **Repetition**
    - Delivering CPR
    - In and out of ambulance
    - Lifting and carrying

BIOMECHANICS OF THE BACK

- The stronger the contractions of the muscles supporting the spine, the greater loads it can withstand

- The human back works like a lever when applying biomechanical principles
HARDER FOR SPINAL MUSCLES

Minimize forward reach to minimize stress on support muscles!

EASIER FOR SPINAL MUSCLES

Minimize forward reach to minimize stress on support muscles!
KEYS TO BACK INJURY PREVENTION

**Plan**
- Know your limits
- Approach all lifts with caution

**Prepare**
- Check your carry path for obstacles

**Position**
- Position yourself to minimize strain

**Posture**
- Keep spine neutral
SAFE PRINCIPLES OF LIFTING

<table>
<thead>
<tr>
<th>Situation</th>
<th>Prepare</th>
<th>Interact</th>
<th>Neutral spine</th>
<th>Execute</th>
<th>Smooth</th>
</tr>
</thead>
</table>

- Evaluate the situation before performing the lift
# SAFE PRINCIPLES OF LIFTING

<table>
<thead>
<tr>
<th>Situation</th>
<th>Prepare</th>
<th>Interact</th>
<th>Neutral spine</th>
<th>Execute</th>
<th>Smooth</th>
</tr>
</thead>
</table>

- Physically and mentally prepare for the lift/transfer

- Communicate with the patient and other responders

- This informs the patient of what will occur, and ensure that all parties are aware of the plan of action
SAFE PRINCIPLES OF LIFTING

- Decreased load on the structures of the spine and its supporting muscles
- Keep core muscles tight to maintain stable spine

SAFE PRINCIPLES OF LIFTING

- Determine the safest route for transferring the object
SAFE PRINCIPLES OF LIFTING

- Avoid sudden or jerky movements, which places stresses on the structures of the spine

MAINTAINING PROPER LIFTING MECHANICS

- Back straight
- Avoid twisting
- Close to body
- Keep smooth and controlled
BACK STRAIGHT

When the spine is flexed:

- Intervertebral discs are in a weaker position
- More difficult to maintain spine stability

To avoid back flexion, bend at the knees and hips instead of the back.

AVOID TWISTING

When the spine is twisted

❖ Discs are x2 weaker when twisted in comparison to when the spine is neutral

The best way to reduce twisting movements is to pivot your feet.
CLOSE TO THE BODY

CLOSE TO THE BODY
KEEP SMOOTH

- Jerking increases the load on the intervertebral discs causing the fibers of the disc to degenerate

AVOID using the Valsalva maneuver (tensing of the core while simultaneously holding breath) when lifting, as it causes the user’s blood pressure to spike suddenly

Keep breathing normally while lifting
Global objectives of safe lifting

Plan

Prepare

Position

Posture
**REVIEW**

Procedural guidelines of safe lifting

- Situation
- Prepare
- Interact
- Neutral spine
- Execute
- Smooth

Helps fulfill the 4 P’s

**REVIEW**

How to lift properly

- Plan ahead before lifting
- Lift close to your body
- Feet shoulder width apart
- Bend at the knees and hips, while keeping back straight
- Tighten core muscles
- Maintain normal breathing
- Test load
- If you are straining, get help