Preventing Back Pain Among Caregivers Using Real-time Movement-centered Feedback

by

Mohammadhasan Owlia

A thesis submitted in conformity with the requirements
for the degree of Master of Applied Science

Department of Mechanical and Industrial Engineering

University of Toronto

© Copyright by Mohammadhasan Owlia (2018)
Abstract

Caregivers are at high risk of back injury from performing care tasks that often require the use of awkward postures. Existing traditional training programs have been shown to be effective at reducing the risk of back injury. The use of real-time feedback during care tasks offers a promising alternative approach.

This thesis reports on the development of a training program based PostureCoach, a wearable device that warns users when the spine if flexed too far forward using real-time feedback.

Novice caregivers (n=16) were asked to perform a series of simulated care tasks. The training program decreased the 80th and 95th percentile of forward flexion values in the intervention group (n=10) by 36.0% and 29.1%, respectively, while no change was seen in the control group (n=6). These results demonstrate the potential of our training program for reducing the risk of back injury for caregivers.
Acknowledgements

First and foremost, I have to extend a heartfelt gratitude to my supervisor, Tilak Dutta. Thank you for providing me with an opportunity to learn and create, and for sharing your insight and guidance with me throughout the past couple of years.

I would like to thank my supervisory committee, Geoff Fernie, Tyson Beach, and Karl Zabjek, for providing me with their valuable feedback.

I am also grateful to all collaborators who helped me in developing the new PostureCoach, as well as all who were involved in the planning, data collection, and analysing stages. Megan Kamachi, Kevin Ledda, Chloe Ng, Pratik Agrawal, Jessie Leith, thank you.

Thanks to AGE-WELL for funding this project.

Finally, I am eternally grateful to my parents for their support, and to my dear Maryam.
Table of Contents

Acknowledgements........................................................................................................................................... iii

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

List of Tables ................................................................................................................................................ viii

List of Figures ................................................................................................................................................ ix

List of Appendices ......................................................................................................................................... xiv

1 Background.................................................................................................................................................... 1

1.1 Musculoskeletal Injuries in Caregivers........................................................................................................ 1

1.1.1 Back Injuries and Back Pain.................................................................................................................... 2

1.2 Anatomy of the Spine.................................................................................................................................. 5

1.2.1 Disc Herniation....................................................................................................................................... 6

1.3 Risk Factors for Back Injury and Pain ........................................................................................................ 8

1.4 Fitting the Task to the Worker vs Fitting the Worker to the Task ...................................................... 10

1.5 Movement-centered Real-time Feedback .................................................................................................. 11

1.6 Wearable Devices for Monitoring Posture ................................................................................................. 12

1.7 The Need to Focus on Achieving Behaviour Change ............................................................................... 13

2 PostureCoach v0.1 ....................................................................................................................................... 14

2.1 Accuracy ...................................................................................................................................................... 15

2.2 Effectiveness ............................................................................................................................................... 17
2.3 Lessons Learned ........................................................................................................ 19

3 Research Questions, Hypotheses and Objectives .................................................... 21

3.1 Research Questions ................................................................................................. 21

3.2 Hypotheses Tested .................................................................................................. 22

3.3 Objectives ................................................................................................................ 22

4 PostureCoach v0.2 .................................................................................................... 24

5 Initial Accuracy Assessment of PostureCoach v0.2 ................................................. 28

5.1 Methods .................................................................................................................. 28

5.1.1 Setting .................................................................................................................. 28

5.1.2 Instrumentation ................................................................................................... 28

5.1.3 Participants .......................................................................................................... 30

5.1.4 Protocol .............................................................................................................. 30

5.1.5 Data Analysis ..................................................................................................... 31

5.2 Results .................................................................................................................... 32

5.3 Discussion .............................................................................................................. 35

6 Accuracy of PostureCoach v0.2 During Simulated Care Tasks ............................. 36

6.1 Methods ................................................................................................................. 36

6.1.1 Setting ............................................................................................................... 36

6.1.2 Instrumentation ................................................................................................. 36
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.1.2</td>
<td>Instrumentation</td>
<td>57</td>
</tr>
<tr>
<td>9.1.3</td>
<td>Participants</td>
<td>57</td>
</tr>
<tr>
<td>9.1.4</td>
<td>Protocol</td>
<td>58</td>
</tr>
<tr>
<td>9.1.5</td>
<td>Data Analysis</td>
<td>58</td>
</tr>
<tr>
<td>9.2</td>
<td>Results</td>
<td>60</td>
</tr>
<tr>
<td>9.3</td>
<td>Discussion</td>
<td>63</td>
</tr>
<tr>
<td>10</td>
<td>Effectiveness of the Training Video</td>
<td>65</td>
</tr>
<tr>
<td>11</td>
<td>General Discussion</td>
<td>67</td>
</tr>
<tr>
<td>12</td>
<td>Conclusions</td>
<td>69</td>
</tr>
<tr>
<td>13</td>
<td>Future Work</td>
<td>71</td>
</tr>
<tr>
<td>13.1</td>
<td>Short Term</td>
<td>71</td>
</tr>
<tr>
<td>13.2</td>
<td>Long Term</td>
<td>71</td>
</tr>
<tr>
<td>14</td>
<td>References</td>
<td>73</td>
</tr>
<tr>
<td>Appendix A</td>
<td>List of Care Activities</td>
<td>78</td>
</tr>
<tr>
<td>Appendix B</td>
<td>Back Injury Prevention Video Questionnaire</td>
<td>79</td>
</tr>
<tr>
<td>Appendix C</td>
<td>Script of Back Injury Prevention Video</td>
<td>81</td>
</tr>
<tr>
<td>Appendix D</td>
<td>Forward Flexion Measured by PostureCoach vs Vicon</td>
<td>86</td>
</tr>
</tbody>
</table>
List of Tables

Table 1. Demographic information of participants included in data analysis ................. 37
Table 2. Demographic information of participants included in data analysis .................. 47
Table 3. Demographic information of participants included in data analysis ................. 57
List of Figures

Figure 1. Incident rates of musculoskeletal disorders by industry. SG, LG and PS denote to State Government, Local Government and Private Sector respectively.......................... 2

Figure 2. Characteristics of occupational injuries in Ontario 2011-2015 (left) Percentage of back injury among workers of different industries - (right) Body parts affect by injury in healthcare workers. ........................................................................................................ 3

Figure 3. The neutral spine ........................................................................................................ 5

Figure 4. Anatomy of a vertebra and an intervertebral disc ................................................. 6

Figure 5. Differences in resultant forces acting on the nucleus pulposus as a result of bending from the hips (left) compared to flexing the spine (right). .............................. 7

Figure 6. The image on the left demonstrates what happens when the lumbar spine is flexed: the discs are deformed and the facet joints are separated, concentrating loads on the disc. In contrast, when lumbar lordosis (natural curve in spine) is maintained (image on the right), the discs maintain their neutral shape and the facet joints help share loads generated through the spine.................................................................................. 8

Figure 7. Schematic of our proposed model of change to reduce risk of back pain/injury for caregivers ......................................................................................................................... 13

Figure 8. The current study in relation to future work.............................................................. 13

Figure 9. PostureCoach v0.1 consisting of two Shimmer sensors attached to 3D printed clips (left), and Android smartphone running the PostureCoach app (right)......................... 14
Figure 10. Schematic representation of the experimental apparatus. The orientation of each rigid clip was measured by both the IMU-based and the optical-based tracking systems.  

Figure 11. Trajectory of angle between two sensors, measured by Vicon (red) and IMUs (Blue) at top, and the discrepancy between those measurements at bottom.  

Figure 12. The average 90th percentile flexion angles recorded for all baseline and coaching trials.  

Figure 13. Main board, which includes microprocessor, SD-card reader, battery and lower sensor and its cover.  

Figure 14. Control board and its cover.  

Figure 15. Upper sensor and its cover.  

Figure 16. The final configuration of PostureCoach v0.2  

Figure 17. Setup of PostureCoach v0.1 and v0.2  

Figure 18. Position of markers, sensors and rigid clusters.  

Figure 19. Setup of the upper (left) and lower (right) sensors  

Figure 20. Bending while moving forward  

Figure 21. Forward flexion measured for a single participant based on Shimmer, Xsens and Vicon for a bending task (top) and a bending-while-walking task (bottom).  

Figure 22. Error for PostureCoach system based on the Shimmer and Xsens sensors for a bending task (top) and a bending-while-walking task (bottom).  

Figure 23. Accuracy of PostureCoach v0.1 and v0.2. Error bars represent standard error.
Figure 24. Distribution of values measured for forward flexion using Shimmer (left) and Xsens (right) compared to Vicon ................................................................. 34

Figure 25. Setup for the PostureCoach accuracy measurement study in TRI’s HomeLab Bedroom (Left) and Living Room (Right) ................................................................. 37

Figure 26. Care activities performed in the bedroom ................................................................. 39

Figure 27. Forward flexion measured using Vicon and PostureCoach for a single participant (top) and their difference (bottom) ................................................................. 40

Figure 28. PostureCoach forward flexion measurement error compared to the Vicon motion capture system. Error bars are based on standard error. ........................................ 41

Figure 29. PostureCoach forward flexion measurement compared to the Vicon motion capture system........................................................................................................ 41

Figure 30. Setup of HomeLab for this study ............................................................................. 45

Figure 31. Schematic of the protocol used for pilot study with control group shown on the left and intervention participants on the right ...................................................... 47

Figure 32. Sample of lumbar spine flexion data measured for a single participant using PostureCoach. The red dashed-line represent the angle between the sensors when participant is standing straight, and is used as the zero for forward flexion in this case. 51

Figure 33. Average histogram of forward spine flexion in intervention group for Trial 1, Trial 2 and Trial 8 trials along with corresponding 95% confidence intervals .................... 51

Figure 34. 50th, 80th and 95th percentile values for normalized forward flexion for the intervention and control groups. The error bars represent standard error. ................. 52

Figure 35. Schematic of the updated protocol used in this study ............................................. 58
Figure 36. Average histogram of forward spine flexion angles (in degrees) in intervention group for Trial 1, Trial 2 and Trial 8 along with corresponding 95% confidence intervals...

Figure 37. 50th, 80th and 95th percentile of forward flexion/maximum flexion across trials in intervention and control groups. Error bars show standard error.

Figure 38. Video effect among individuals in intervention group. Error bars show standard error.

Figure 39. Overview of program and repetition effects. The left bar in each group of each graph corresponds to the Trial 1 and the right one to the Trial 8. Error bars show standard error.

Figure 40. Participants’ scores on the back injury prevention questionnaire before watching the video and after watching the video.

Figure 41. Forward flexion measure by PostureCoach compared to Vicon for Participant #1.

Figure 42. Forward flexion measure by PostureCoach compared to Vicon for Participant #2.

Figure 43. Forward flexion measure by PostureCoach compared to Vicon for Participant #3.

Figure 44. Forward flexion measure by PostureCoach compared to Vicon for Participant #4.

Figure 45. Forward flexion measure by PostureCoach compared to Vicon for Participant #5.
Figure 46. Forward flexion measure by PostureCoach compared to Vicon for Participant #6. ................................................................. 88

Figure 47. Forward flexion measure by PostureCoach compared to Vicon for Participant #7. ................................................................. 89

Figure 48. Forward flexion measure by PostureCoach compared to Vicon for Participant #8. ................................................................. 89
List of Appendices

Appendix A: List of Care Activities ................................................................. 78

Appendix B: Back Injury Prevention Video Questionnaire ............................... 79

Appendix C: Script of Back Injury Prevention Video .................................... 81

Appendix D: Forward Flexion Measured by PostureCoach vs Vicon .............. 86
1 Background

Caregivers are at high risk of developing musculoskeletal injuries. In this section, I look at the scope of this problem, with a special focus on back injuries and review the previous work that has gone into reducing the risk of back injuries for caregivers and consider promising novel methods.

1.1 Musculoskeletal Injuries in Caregivers

Musculoskeletal (MSK) injuries are a major public health burden that result in large economic costs across many industries, not to mention the personal costs to those who suffer from the resulting pain [1]. Healthcare providers in hospitals, nursing homes, and in the community, as well as family caregivers who take care of their relatives in their homes are at risk of back injury/pain. The trend of shifting patient care from hospitals to home, with 2.2 million Canadians receiving care at home, has increased the burden on homecare workers as well as family caregivers. Patient handling tasks often require lifting heavy loads while maintaining extreme postures because of space constraints and the lack of equipment [2-5].

While the rate of most of occupational injuries across all industries has been declining over the past decades, the rate of musculoskeletal injuries among healthcare workers has remained high [6]. In the United states, incident rate for musculoskeletal injuries was reported to be 8.8% and 13.5% in hospital and nursing home settings, respectively [2]. In general, healthcare workers are injured at higher rates than workers in many
industries such as construction or maintenance and repair that have been traditionally considered higher risk (Figure 1) [7].

![Figure 1. Incident rates of musculoskeletal disorders by industry [7]. SG, LG and PS denote to State Government, Local Government and Private Sector respectively.]

1.1.1 Back Injuries and Back Pain

In particular, the proportion of back injuries in healthcare sector is more than any other occupation group, as is demonstrated in Figure 2. Five percent of healthcare workers in Ontario report back injury each year [8], which results more lost time and higher compensation cost compared to all other types of injury [9].
The fact that back injuries cause the most lost work days per injury [10], and they have relatively high compensation costs when compared to other injuries, adds to the importance of addressing this issue among healthcare workers [11].

Many caregivers who do not report a back injury may still suffer from back pain. Data from over 80 studies reveal that back pain in caregivers has a worldwide prevalence of 40-50% and a lifetime prevalence of 35-80% [12]. As a comparison, rate of back pain among general population is estimated to be 15-20% [11]. It is no surprise that low back pain (LBP) is a major reason for healthcare workers to leave their jobs [13].

Figure 2. Characteristics of occupational injuries in Ontario 2011-2015 (left) Percentage of back injury among workers of different industries - (right) Body parts affect by injury in healthcare workers [8].
Many studies have reported that the burden of LBP is more than any other disability [14-16]. A recent review revealed that among 291 conditions studied in the Global Burden of Disease 2010 Study [17], LBP is the most important cause of global disability in terms of “years lived with disability” and sixth greatest contributor in terms of “disability-adjusted life years” [18].

It was estimated that between 1994 to 1995 in Great Britain, nearly 116 million work days were lost as a result of LBP [19], which would translate into roughly $160 billion of lost productivity [20]. More recent studies have estimated annual cost of LBP to be around $100 to 170 billion [21, 22].

Even though usually back pain decreases rapidly in the first month [23], most patients continue to suffer from symptoms within the following year [24]. The recurrence of low back pain is also very high, with approximately a third of those who experience LBP suffering from three or more episodes within a year [25].

Back pain/injury has a two-fold negative impact on our healthcare system because these conditions reduce capacity in the system by removing caregivers while simultaneously creating new patients. Perhaps most importantly, back injuries/pain can have a dramatic impact on an individual's life outside of work. Many live with chronic pain and suffering that can severely limit activity and engagement in their personal lives as well as professionally [26].
The following section reviews some basic spine anatomy and what happens when things go wrong.

1.2 Anatomy of the Spine

When healthy individuals stand in neutral posture, there are three curves are present in the spine:

- A lordosis (inward curve) that begins from skull and ends where neck reaches torso, called cervical spine.
- A kyphosis (outward curve) beginning between shoulders and ends at the bottom of ribcage, called thoracic spine.
- A lordosis (inward curve) which begins at the bottom of ribcage and extends to the pelvis, called lumbar spine.

![Figure 3. The neutral spine](image)

The spine consists of a series of bones (vertebrae) separated by intervertebral discs in between. Each disc contains a pressurized gel-like material called the nucleus pulposus, surrounded by outer rings of collagen called the annulus fibrosus. This structure has the
ability to be deformed while supporting heavy loads, much like a car tire. Each vertebra has bony protrusions called processes, which serve as anchoring points for muscles and ligaments, and can be felt as small bumps through the skin on an individual’s back. These processes include facet joints, which provide locations for the vertebra to seat against each other when the spine is in neutral posture to help the tissues of the spine support compressive and shear loads. These joints also help guide the motion of each vertebra when the spine bends or twists.

The spinal cord (the body’s main nerve pathway) travels down along the spine from the brain, with multiple nerve roots exiting the spine at each joint. These nerves can get irritated or pinched following breakdown of the other tissues of the spine with injury or overuse, causing pain locally or along the length of nerve.

![Figure 4. Anatomy of a vertebra and an intervertebral disc](image)

1.2.1 Disc Herniation

When the lumbar spine is flexed in the sagittal plane, the discs deform to support this motion (Figure 5). This deformation results in a resultant force acting on the nucleus pulposus that pushes it posteriorly. Over time and with repetitive combined loading (flexion and compression), the nucleus pulposus may begin travel outward through the
layers of the disc annulus fibrosus as the layers of collagen separate under the repeated stresses. This movement can lead to a herniated disc [27].

Figure 5. Differences in resultant forces acting on the nucleus pulposus as a result of bending from the hips (left) compared to flexing the spine (right) [28].

One way to prevent this type of injury is to minimize sagittal spine flexion to maintain lumbar lordosis. Rather, bending should be focused at the hips instead – sometimes called “hip-hinging”. Another important benefit of maintaining lumbar lordosis during lifting is that in this position, the facet joints will be in contact resulting in reduced forces on the discs because the vertebrae are able to share some of the load (Figure 6) [29-32].
Therefore, one method for preventing back injury is to reduce the amount of sagittal spine flexion. This can be achieved by maintaining the lordosis in the lumbar spine while bending at the hips, as the spine is in its strongest state when in its neutral posture.

The following section reviews the risk factors for back injury and back pain from the literature and underscores the importance of reducing sagittal spine flexion for reducing risk.

1.3 Risk Factors for Back Injury and Pain

A number of studies have focused on identifying underlining risk factors for low back injury and pain [25, 33, 34]. These risk factors can be categorized in three groups:

- **Personal factors** such as genetics, gender, age, weight, height, physical activity, and BMI [35].

- **Psycho-social factors** such as depression, stress, and anxiety [36, 37].

- **Occupational factors** including body posture and position, whole body vibration, etc. [38].
In the first two categories, only previous episodes of LBP have been identified as a strong predictor of LBP risk [39], while studies have not found conclusive evidence for a relationship between LBP and other proposed risk factors. However, studies have shown that occupational factors can predict back pain and injury.

Manual handling is considered a major occupational risk factor for back injury [40, 41]. Heavy and repetitive lifting with a flexed lumbar spine puts individuals at a high risk for developing lower back pain and injury [42-44]. In particular, eighty percent of all spinal injuries affect the lumbar spine [45].

The magnitude and frequency of trunk flexion, time spent in a forward flexed trunk or non-neutral postures and trunk movements with high angular velocity can predict back pain [46-50]. Limited experience in patient handling skills, as well as poor posture while lifting objects weighing more than 10 kilograms, have been reported as major contributors to lower back pain among caregivers [50, 51].

Biomechanical studies support these epidemiological findings by showing that fatigue failure of spine happens with extreme flexions, i.e. near the end of range of motion of spine [52, 53]. Utilizing more spine flexion also increases compression, torsion, and shear forces on the lumbar spine [29-31], and in therefore significantly increase the chance of developing herniated discs and/or other tissue damage to the structures of the spine [27, 54, 55].
1.4 Fitting the Task to the Worker vs Fitting the Worker to the Task

Approaches to prevent lower back pain among workers can be categorized into two approaches: those that fit the task to the worker and those that fit the worker to the task.

The most common approach taken over the past few decades has been fitting tasks to the worker [56]. For instance, mechanical patient lifting devices have been widely introduced in healthcare institutions to reduce the need for physical strength in order to lift or transfer a patient. These devices have been shown to reduce the LBP risk [57-59].

There are major limitations for the above-mentioned approaches. Using patient lifting devices introduce new activities such as sling insertion that may also cause injury [60]. In the case of homecare workers and family caregivers, mechanical lifts are still not widely utilized. Even in hospital settings, many tasks are yet to be redesigned to fit the worker by reducing the loads generated on the low back such as re-positioning patients in bed, toileting and bathing [6, 61].

The limitations of the first approach highlight the importance of not overlooking the second one: fitting the worker to the task. In fact, in his position paper, McGill argues that we may have already realized the bulk of the benefits of the first approach and future gains will be found through the second approach [56]. Traditionally, these methods have included training about body mechanics, ergonomics and safe handling. For instance, in the training sessions, workers maybe told to maintain lumbar lordosis during lifting and avoid stooping (Figure 6), keeping the load close to the body when...
lifting, etc. These educational programs are often called “back school” or “back education sessions” and were first developed in Sweden in 1969 [62, 63]. Low back postural training is also a common prescription of physiotherapists for managing and rehabilitation individuals with lower back pain [28].

However, studies have shown that these educational interventions, focusing on biomechanical models are not effective in preventing LBP [64, 65]. In particular, it is difficult to achieve long term behavior change using these methods [66, 67].

Additionally, different types of equipment, caregiving settings, patient needs and level of cooperation makes it necessary to implement various patient handling techniques [2]. For example, when providing care in the home, space constraints and lack of equipment will result in completing tasks with methods that are far from ideal [6].

Such limitations put family and informal caregivers at perhaps the highest risk, as they tend to have no training on caregiving techniques and limited equipment [68]. We know that over half of incidents of lower back pain happen in the first year of employment and among young, inexperienced workers [69]. The ongoing trend to shift care from hospitals to homes in many jurisdictions adds to the urgency of addressing these concerns.

1.5 Movement-centered Real-time Feedback

In contrast to traditional classroom-based educational programs, movement-centered task-specific feedback has the potential for reducing unsafe postures and subsequently
the risk of back injury among workers [70]. For instance, auditory feedback based on body posture tracked with electromagnetic system has been shown to reduce the amount of spine loading, flexion and bending among warehouse workers [71].

A key to improve a given type of feedback's educational effectiveness is its timeliness [72]. A computer-aided system with real-time feedback based on spinal positioning was found to be helpful during physiotherapy exercises [73]. Other studies found wearable real-time feedback useful for a variety of applications [74-77]. A few studies have suggested that use of real-time feedback is effective in improving spinal posture [78-84].

The following section will review the wearable devices that are available on the market today for providing real-time feedback based on spine posture.

1.6 Wearable Devices for Monitoring Posture

Currently there are seven wearable devices on the market for providing feedback based on spine posture [85-91], six of which use a single inertial motion unit (IMU) for doing so. These single-sensor devices typically track the orientation of the trunk as one segment and are not sophisticated enough for measuring lumbar spine flexion. In the context of providing care, in which bending is necessary and bending correctly with neutral spine is desired, the aforementioned devices are incapable of providing appropriate posture-based feedback. While the seventh device, Backtone [89], does provide feedback based on spine flexion, it does not have the ability to record data.
1.7 The Need to Focus on Achieving Behaviour Change

In order to see a reduction in injury risk, we hypothesize a caregiver needs to progress through two stages. First, he or she will need to develop a basic understanding of key principles of ergonomics. In our case, we need each participant to understand that bending from the hips rather than flexing the spine is beneficial for reducing the risk of back pain/injury. But having this knowledge alone will not reduce risk of injury if it does not lead to a change in behavior. Caregivers need support in achieving the target behavior change. In our case, we hypothesize that our recently developed device called PostureCoach may support this goal of achieving behavior change by providing real-time auditory feedback. Figure 7 shows a schematic of my proposed model of change.

![Figure 7. Schematic of our proposed model of change to reduce risk of back pain/injury for caregivers](image)

This project paves the way for future studies to investigate the long-term effectiveness of a wearable device with real-time posture-based feedback in reducing the back pain/injury for caregivers in real-world settings, as shown in Figure 8.

![Figure 8. The current study in relation to future work](image)
2 PostureCoach v0.1

PostureCoach v0.1 was previously developed in our lab in 2015-2016. The device consisted of a pair of Shimmer3 (Shimmer Sensing, Dublin, Ireland) nine degree-of-freedom inertial motion units (IMUs) and a smartphone. There are many different brands of IMUs available on the market but most are based on a similar design. Typically, they combine information from tri-axial accelerometers, gyroscopes and magnetometers to calculate orientation in space by referencing gravity and earth's magnetic field.

The IMUs were attached to a torso harness and a belt using 3D printed plastic clips. The belt and harness were used to hold the upper and lower sensors on an individual’s back at the mid-thoracic level and near the sacrum, respectively.

![PostureCoach v0.1 consisting of two Shimmer sensors attached to 3D printed clips (left), and Android smartphone running the PostureCoach app (right).](image)

A custom android application [92] was developed to run on the smartphone communicated with IMUs through Bluetooth. Figure 9 shows the components of the
system. The app allowed users to set thresholds for forward flexion, lateral bending and twisting. The application utilized the sensors' orientation in a calibration posture (standing upright) as a reference for measuring changes in spine posture. The app had the ability to provide auditory (beep) and/or tactile (vibration) feedback when preset thresholds were exceeded.

Two evaluations were done with this initial prototype: a measurement of accuracy of the system; and an assessment of the effectiveness of the system for movement retraining for reducing the time spent in end-of-range spine flexion.

![Definitions of flexion, lateral bend and twist.](image)

**Figure x.** Definitions of flexion, lateral bend and twist.

2.1 Accuracy

Semple et al. (2015) added reflective markers to the rigid clips that held the Shimmer sensors to allow a Vicon motion capture system to measure accuracy of spine angles measured with the system (shown in Figure 10). A Vicon motion capture system (MX3+)
tracked the position of rigid clips in space at 100Hz, while IMU's were tracking orientation of them at 102Hz.

The clips were held in an initial upright position, similar to standing straight, for 10 seconds. Afterwards, clips were slowly swept through motions about each of the primary axes, covering approximately ±60° about each axis.

Figure 10. Schematic representation of the experimental apparatus. The orientation of each rigid clip was measured by both the IMU-based and the optical-based tracking systems.

When compared against the Vicon system, the Shimmer IMUs were able to track forward bending, lateral bending, and twisting with mean RMS errors of 2.9° ± 2.0°, 2.3° ± 1.6°, and 4.9° ± 3.3°, respectively. However, it is important to note that maximum errors were found to be up to three times larger. Figure 11 shows angle measurements from one trial for the Shimmer IMU showing that the maximum angular errors were on the order of 10 degrees for all three measurement axes.
Figure 11. Trajectory of angle between two sensors, measured by Vicon (red) and IMUs (Blue) at top, and the discrepancy between those measurements at bottom.

2.2 Effectiveness

Ford et al. (2016) ran a pilot test on PostureCoach v0.1 to determine if it was able to reduce the time participants spent in end-of-range spine flexion during a series of simulated patient handling tasks, and to identify potential improvements to the system. The focus of this study was limited to spine flexion since the previous study on accuracy of the system demonstrated there was the highest signal to noise ratio in the spine flexion measurement compared to lateral bending and twisting.

Eighteen participants were recruited from three populations (six novice caregivers, six student clinicians and six professional clinicians) were asked to perform following list of simulated care activities on a standardized patient:

- Place a sling under the patient
- Transfer the patient from hospital bed to a manual wheelchair positioned beside the bed
• Wheel the patient to the toilet and helping him to stand, doff his pants, and sit on the toilet

Participants were first asked to perform the care activities with no feedback from PostureCoach (baseline). Participants then repeated the same tasks while receiving auditory feedback using the 90th percentile flexion angle from the baseline trial as the feedback threshold.

Results showed that while novices and student clinicians had reductions in 90th percentile flexion angle, professional clinicians did not show any significant change (Figure 12).

![Figure 12. The average 90th percentile flexion angles recorded for all baseline and coaching trials.](image-url)
2.3 Lessons Learned

While the initial prototype of the system did show promise, a number of serious limitations were identified:

- The low accuracy of the Shimmer sensors provided inconsistent feedback to the participants with false activations being the most problematic. In some cases, the system would produce a warning tone even as participants walked forward or turned quickly while standing upright with neutral spine posture. This observation suggested that the sensor accuracy measurement (section 2.1) may have not captured a representative assessment of the errors with the system since the accuracy was measured with the sensors moving smoothly about a single axis. Instead, the assessment should have included more complex motions as well as those that were representative of caregivers performing care tasks.
  - In the current work, a new version of PostureCoach (v0.2) was developed based on a higher accuracy IMU (MTi-1, Xsens Technologies, Enschede, Netherlands). The accuracy of these sensors was more carefully analyzed using complex movements on multiple axes that have the potential to generate unwanted cross talk across axes.
  - PostureCoach v0.2 was designed to limit sagittal lumbar spine flexion, as the signal to noise ratio for lateral bending and twisting were considerably lower. These changes should reduce the likelihood of false activations that confused participants using v0.1.
• The lack of a control group in the pilot study made it impossible to rule out a repetition effect as an explanation for differences between baseline and coaching trials.
  
  o In the current work, a control group was.

• The harness used for mounting the sensors allowed the IMUs to shift too easily. Also, the position of upper sensor (mid-thoracic level) was too high for isolating movement of the lumbar spine.
  
  o An improved harness system was included in the development of the current system and the location of the upper sensor moved lower (near T10).

• Pairing Bluetooth sensors with the app for each use was found to be too time consuming for users.
  
  o PostureCoach v0.2 was created to be a standalone device with wired connections between sensors and a simpler user interface.
3 Research Questions, Hypotheses and Objectives

The overall goal of this work was to design and evaluate a back injury training program for caregivers that would help shift users’ behaviour to reduce the amount of end-of-range spine flexion utilized while performing patient care activities. The training program tested included the use of a new version of PostureCoach (v0.2) that was designed to address the limitations of its predecessor.

3.1 Research Questions

The specific research questions investigated in this work are listed below.

Primary research questions:

**Q1.** How accurately can spine flexion be measured using PostureCoach v0.2, when compared to a gold standard optical motion capture system and the previous version (PostureCoach v0.1)?

**Q2.** Does a back injury prevention training program, consisting of an educational video and feedback from PostureCoach, change the distribution of spine flexion angles (50th, 80th and 95th percentile values) for novice caregivers (program effect)?

Secondary research questions:

**Q3.** Does a back injury prevention training video change the distribution of spine flexion angles (50th, 80th and 95th percentile values) for novice caregivers (video effect)?
Q4. Does repeating a series of care tasks eight times, without video or PostureCoach feedback, change the distribution of spine flexion angles (50th, 80th and 95th percentile values) for novice caregivers (repetition effect)?

3.2 Hypotheses Tested

I hypothesised the following answers for the research questions:

H1: The accuracy of the current version of PostureCoach (version 0.2) will be higher than for the previous version (v0.1)

H2: PostureCoach will reduce 50th, 80th and 95th percentile spine flexion angles for the individuals in the intervention group more than for the control group.

H3: The back injury prevention training video will reduce spine flexion angles (50th, 80th and 95th percentile values) for novice caregivers.

H4: Repeating a series of care tasks eight times will reduce spine flexion angles (50th, 80th and 95th percentile) for novice caregivers, but this reduction will be much less than the intervention group.

3.3 Objectives

In order to answer the research questions listed above, the following objectives were defined and achieved:

O1: Develop PostureCoach v0.2 to track lumbar spine posture and provide real-time movement-centred feedback
O2: Measure the accuracy of PostureCoach v0.2 by comparing to a gold standard motion capture system.

O3: Create a training video for teaching the importance of reducing the extreme spine flexion during caregiving activities.

O4: Measure the effectiveness of the training program (training video + PostureCoach v0.2) in changing the distribution of forward flexion angles over time compared to the control group.

O5: Measure knowledge transfer and change in distribution of forward flexion resulting from a training video viewed by novice caregivers.

Chapter 4 describes the development of PostureCoach v0.2 (O1) building on the lessons learned from the previous version (described in section 2.3). Chapters 5 and 6 describe two investigations of the accuracy of the new system (O2). Chapter 7 describes the development of our back injury prevention training video (O3). Next, the effectiveness of our training program is evaluated in a pilot study reported described in chapter 8 and full study in chapter 9 (O4). Finally, I report on the knowledge transfer and changes to forward spine flexion in chapter 10 (O5).

Note that the second and fourth questions (Q1 and Q2) were modified based on the results of the pilot study (chapter 8) based on the comments of supervisory committee. The participants in the control group watched a training video in my pilot study (chapter 8) but not in the main study (chapter 9).
4 PostureCoach v0.2

PostureCoach v0.2 was designed to address the limitations of the initial prototype described in section 2. It was designed as a standalone device that operated without the need for a smartphone to be paired over Bluetooth. To keep the prototype simple to build and use, wired connections were used between components.

In this version, a pair of MTi-3 (Xsens Technologies, Enschede, Netherlands) inertial measurement units were used to measure flexion of the lumbar spine. Each IMU combined information from tri-axial accelerometers, gyroscopes and magnetometers to calculate its orientation in space by referencing gravity and earth’s magnetic field. An M3 32-bit microcontroller was used for reading the sensors’ output and for determining their relative orientations of the upper and lower regions of the lumbar spine. The relative angle between the two sensors was decomposed based on the orientation of lower sensor. Finally, the angle about the mediolateral axis, was used to represent the amount of lumbar spine flexion. The microprocessor was programmed to activate wither audible or tactile feedback when the spine flexion angle exceeded a pre-defined threshold. The output of both sensors was also recorded on an SD-card. Figure 13 illustrates the core components of the main board. This part was attached to a sacroiliac belt (Serola Biomechanics, Inc., Loves Park, IL) using velcro, to be placed near the sacrum.
Figure 13. Main board, which includes microprocessor, SD-card reader, battery and lower sensor and its cover.

A control board was designed and fabricated to help the user visualize the acquired data and capture user commands. It included a set of control switches and an LCD screen and was attached to the belt in a location that could be accessed by the user. Figure 14 shows a rendering of the control board part of the system.

Figure 14. Control board and its cover.
The third and final component making up PostureCoach v0.2 was the upper sensor that was hard-wired to the main board and was mounted on the vest with double-sided tape such that it was positioned over the T10 vertebral process. Figure 15 shows the upper sensor component.

![Connection to Main Board IMU](image)

*Figure 15. Upper sensor and its cover.*

To put on the device, users first donned the belt and vest and then a member of the research team would place the control and main boards on the appropriate locations of belt followed by the upper sensor on the vest near T10, as shown in Figure 16.

![The final configuration of PostureCoach v0.2](image)

*Figure 16. The final configuration of PostureCoach v0.2*
The casing of each board was designed in SolidWorks (Dassault Systèmes, Vélizy-Villacoublay, France) and produced using rapid prototyping. The bottom and top halves of main and control board casings were fastened using hex nuts and screws. The casing for the small upper sensor was designed to be press-fit.

PostureCoach had the ability to provide both auditory and/or tactile (vibration) feedback. However, we decided to continue using audio cues for this research, as it was easier to identify by all participants as well as members of research team.
5 Initial Accuracy Assessment of PostureCoach v0.2

This section describes the results of a pilot validation of PostureCoach v0.2 which involved participants wearing the device while performing a series of movements while spine flexion angles were tracked by both PostureCoach systems (v0.1 and v0.2) and a gold standard Vicon motion capture system.

5.1 Methods

5.1.1 Setting

This study took place in FallsLab, located on the 12th floor of Toronto Rehabilitation Institute. This lab has a 10 camera Vicon optical motion capture system installed for tracking the 3D location of reflective markers, along with Vicon Nexus (1.8.5) software for data processing. This lab also included a motion platform, which was locked in static position for the duration of this study.

5.1.2 Instrumentation

The inertial measurement units (IMUs) used in the newest version of the system (PostureCoach v0.2), MTi-3 (Xsens Technologies, Enschede, Netherlands), as well as the sensors of the previous version (PostureCoach v0.1), Shimmer3 IMUs (Shimmer Inc., Dublin, Ireland), were mounted to participants, as shown in Figure 17. The upper sensors were positioned at T10, while the lower ones were placed near the sacrum, secured with a sacroiliac belt (Serola Biomechanics, Inc., Loves Park, IL).
In order to collect kinematic data using Vicon motion capture system, eight tracking and six landmarking reflective markers were placed bilaterally on the acromion, posterior superior iliac crest and greater trochanter of participants, as shown in Figure 18.

Tracking markers were directly attached to the rigid bodies that hold upper and lower sensors, as can be seen in Figure 19.
The output of PostureCoach v0.1 was recorded using a MATLAB program on a laptop computer that communicated with both sensors over Bluetooth. PostureCoach v0.2 saved the orientation of sensors in an SD card and Vicon’s output was captured using a PC running Nexus (1.8.5) software.

5.1.3 Participants

A convenience sample of four healthy adults were recruited for this study.

5.1.4 Protocol

After donning the belt and vest that mount calibration markers and IMU sensors on participants, reflective markers were placed on them. A ten second static calibration trial was also collected to aid with constructing each individual’s model using Visual3D software. Following static calibration, subjects were asked to perform a number of movements, twice each. These movements were selected to include a range of natural movements including one that had the potential to generate cross talk in the IMUs that I suspect resulted in false activations in PostureCoach v0.1.
Participants were asked to start from a neutral standing posture and:

- Do a toe-touch, with a self-selected pace (maximum forward flexion)
- Bend as they would do in real life, with a self-selected pace
- Bend slowly
- Bend as fast as possible
- Bend forward while walking forward, and stand straight while walking back, as shown in Figure 20

![Figure 20. Bending while moving forward](image)

5.1.5 Data Analysis

The motion capture data, collected at 100Hz, was labeled in Nexus software and exported to Visual3D. After pre-processing the marker data, which included using a cubic spline for interpolating a maximum of continuous 10 frames and low-pass fourth-order Butterworth filtering at 50Hz, a model was constructed for each individual based on the landmarks. Orientation of thorax segment in pelvis coordination system was calculated. The initial orientation of these two segments, obtained in static calibration, was used to set the zero values. Finally, it was decomposed to get the rotation around mediolateral axis, before exporting out of Visual3D as an ASCII file.
The IMU data, collected at 20Hz for PostureCoach v0.2 and 50Hz for v0.1, was processed in MATLAB (MathWorks Inc., Natick, MA) to determine orientation of each sensor relative to the lab coordination system, and to calculate the relative orientation between sensors. To do so, orientation data was converted from Euler angles (PostureCoach v0.2) and quaternions (PostureCoach v0.1) into rotation matrices. All signals were zeroed based on the static calibration. Afterwards, ASCII output of Visual3D was imported to MATLAB and was synced manually with the processed IMU outputs.

The signals with lower sample rate (PostureCoach v0.2), was resampled to 50Hz, before using a MATLAB function [93] to align the signals.

5.2 Results

The lumbar sagittal spine flexion measured using all three systems is shown in Figure 21 for a single participant. These outputs were used to estimate the RMS error for both versions of PostureCoach, compared to the gold standard Vicon motion capture system (Figure 22).
Root-mean-square (RMS) error relative to the Vicon output was used as the measure for quantifying the performance of each system. The results are shown in Figure 23. Figure 24 shows a comparison of the Shimmer (left) and Xsens (right) sensors with Vicon.

The RMS errors for PostureCoach v0.1 and v0.2 are $34^\circ \pm 5.1^\circ$ and $2.0^\circ \pm 1.6^\circ$, respectively.
Figure 23. Accuracy of PostureCoach v0.1 and v0.2. Error bars represent standard error.

Figure 24. Distribution of values measured for forward flexion using Shimmer (left) and Xsens (right) compared to Vicon
5.3 Discussion

The error for PostureCoach v0.1, based on Shimmer sensors, were large even compared to the previous accuracy assessment of this system described in section 2.1. At least part of this error was a result of signal drift. Therefore, I decided to adjust the zero for all Shimmer signals using a data point just prior to each task, rather than rely only on the initial static calibration.

In contrast, the errors for the new version (PostureCoach v0.2) are much smaller and demonstrate that the Xsens sensors are much more robust to signal drift and hold closely to the gold standard motion capture system estimates for spine flexion. It is possible this difference may be due to Xsens having a higher quality hardware (the physical sensor) or a more robust sensor fusion algorithm than the Shimmer system, though it is difficult to know since both the hardware and algorithm designs are proprietary.
6  Accuracy of PostureCoach v0.2 During Simulated Care Tasks

The movements captured in the previous investigation were not designed to be representative of care activities that end users would normally perform. Therefore, the validation study described in this section was done to ensure the device was able to accurately estimate spine flexion angles during a series of simulated patient care activities in a typical homecare setting.

6.1  Methods

6.1.1  Setting

This study took place in HomeLab, located on the 12th floor of Toronto Rehabilitation Institute, which consisted of a furnished bedroom, living room, bathroom and kitchen. This space resembled a typical single-story house with functioning wiring and plumbing, similar to homes where family caregivers would perform daily care activities. This setting allowed us to investigate the accuracy of PostureCoach v0.2 in the presence of possible interference with items typically found in the home setting (e.g. TV, metal bed, and etc.). The potential interference is caused by ferromagnetic materials, which have the potential to create local distortions in the earth’s magnetic field that the magnetometers in our IMUs rely on for tracking heading angles. Figure 25 shows the setting for this study.

6.1.2  Instrumentation

Participants were asked to put on PostureCoach v0.2, which is based on a pair of Xsens IMUs, using a vest and a belt described in chapter 4. Four reflective markers were
attached near each sensor as rigid clusters to allow tracking of the lumbar spine flexion angle using a set of three Vicon MX3+ cameras that were used as the gold standard for comparison. An additional six reflective markers were placed bilaterally on the acromion, posterior superior iliac crest and greater trochanter of participants, as is shown in Figure 18.

Unfortunately, space restrictions prevented the motion capture system from being set up in the bathroom. Therefore, the simulated care activities measured included in this study were restricted to the bedroom and living room.

6.1.3 Participants

A convenience sample of eight healthy adults were recruited to participate in this study. These participants are described in Table 1.

Table 1. Demographic information of participants included in data analysis (Mean ± SD values reported where applicable)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>29.6 ± 14.5</td>
</tr>
<tr>
<td>Sex</td>
<td>4 female; 4 male</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>171.7 ± 4.2</td>
</tr>
<tr>
<td>Mass (Kg)</td>
<td>73.8 ± 8.5</td>
</tr>
</tbody>
</table>
6.1.4 Protocol

After donning the belt and vest that mount calibration markers and IMU sensors on participants, reflective markers were placed on them. A ten second static calibration trial was collected to aid with constructing each participant’s model in Visual3D.

Following static calibration, subjects were asked to repeat each of the following activities twice in the bedroom and twice in the living room. In the bedroom, the patient actor was transferred in and out of bed while in the living room, the patient was helped on and off the couch:

- Maximum spine flexion activity (toe-touch)
- Engage the brakes on wheelchair
- Move the footrests out the way
- Help a patient actor off bed/couch and into wheelchair
- Stand straight for a few seconds and then return the patient back onto the bed/couch
- Maximum spine flexion activity (toe-touch)

Each set of activities was book-ended with a maximum spine flexion activity to allow for synchronizing trials for processing. Figure 26 show a selection of the care tasks participants were asked to perform.
6.1.5 Data Analysis

The motion capture data, collected at 100Hz, was labeled in Nexus software and exported to Visual3D. After pre-processing marker information, which included using a cubic spline for interpolating a maximum of continuous 10 frames and low-pass fourth-order Butterworth filtering at 20Hz, a model was constructed for each individual. The orientation of the upper and lower sensors was calculated. The initial orientation of these two segments, obtained in static calibration, was used to define the zero values of each 3D orientation. Finally, the difference between the two sensors was computed and decomposed to get the spine flexion estimate (rotation about the mediolateral axis) before exporting out of Visual3D as an ASCII file.

The IMU data, collected at 20Hz, was processed in MATLAB to determine orientation of each sensor relative to the lab coordinate system, and the relative orientation between the two sensors was calculated. To do so, orientation data was converted from Euler angles into rotation matrices and all signals were zeroed based on static calibration.

Figure 26. Care activities performed in the bedroom
data. Afterwards, ASCII output from Visual3D was imported to MATLAB and was synced manually with the processed IMU outputs.

A MATLAB function [93] was used to align the signals. Finally, the mean RMS error was calculated along with the Pearson correlation coefficient and both were used to determine accuracy of PostureCoach in the home setting.

6.2 Results

Figure 27 shows a representative plot of the forward spine flexion as measured using both the Vicon and PostureCoach systems for one trial from one participant.

![Figure 27](image)

*Figure 27. Forward flexion measured using Vicon and PostureCoach for a single participant (top) and their difference (bottom)*

Figure 28 shows the accuracy of this IMU based system to determine the amount of sagittal lumbar spine flexion for all points during trials. The overall RMS error was $2.3^\circ \pm$
$0.7^\circ$ and $r = .986$ (Pearson correlation coefficient) when compared with the Vicon system.

**Figure 28.** PostureCoach forward flexion measurement error compared to the Vicon motion capture system. Error bars are based on standard error.

**Figure 29.** PostureCoach forward flexion measurement compared to the Vicon motion capture system.

Figure 29 shows the distribution of forward flexion values measured using PostureCoach (y axis) compared to Vicon (x axis). This plot is presented as a heat map to show where
there is a large number of overlapping points that fall on top of each other (yellow areas).

6.3 Discussion

The results of this study demonstrate that there is close agreement between PostureCoach v0.2 and the gold standard Vicon system. It may be important to note that the RMS error calculated in this study (2.3°) was larger than that calculated in chapter 5 (In FallsLab setting). This may indicate that the environment and/or tasks performed could affect the accuracy of the spine flexion measurement.

When we compare the error in forward flexion measured by PostureCoach v0.2 with the average signal size (≈ 40° based on Figure 29, determined by dividing difference of maximum (≈ 80°) and minimum (≈ 0°) of signal by two), it can be argued that the PostureCoach (v0.2) is capable of estimating spine flexion angle with approximately 6% error. This low signal to noise ratio should be able to provide robust real-time feedback.
7 Development of a Back Injury Prevention Training Video

As discussed in section 1.7, we proposed that the real-time posture-based biofeedback from PostureCoach v0.2 will serve as the missing link between “understanding ergonomics” and “change in behaviour” in our model of change to reduce the risk of back injury by better fitting the worker to the task.

Therefore, we needed to make sure that before using PostureCoach, participants understand that the feedback from the device is prompting them to reduce the amount of spine flexion utilized during the care tasks.

To this end, we designed a back injury prevention training video that included basic information on anatomy and biomechanics of spine as well as how the tissues and structures of the spine can become damaged over time and how this damage can be prevented. The video (https://youtu.be/vtDGheJlfh4) was developed in collaboration with the Occupational Health & Wellness team at Saint Elizabeth Healthcare. The points discussed in the video were adapted from [32, 56, 94].

The script used for the video is included in Appendix C: Script of Back Injury Prevention Video.
8 Pilot Study on Effectiveness of PostureCoach v0.2

This chapter describes my pilot evaluation of the effectiveness of PostureCoach v0.2 in conjunction with a back injury prevention training video in reducing the amount of time participants spent in end-of-range spine flexion, compared to participants who only watched a training video, in a convenience sample of inexperienced individuals.

Eleven novice participants were recruited and divided into two groups: intervention ($n_i = 9$) and control ($n_c = 2$). They were asked to repeat a set of simulated care activities eight times over two separate sessions held on consecutive days. Individuals in intervention group received real-time auditory feedback in some trials when their forward spine flexion exceeded a threshold, while the participants in the control group did not. The change in the amount of forward flexion in the lumbar spine was compared between groups and across trials.

I hypothesized that the real-time feedback from the PostureCoach system would reduce the amount of time spent in extreme spinal flexion among the individuals in the intervention group compared to the control group.

8.1 Methods

8.1.1 Setting

This study took place in HomeLab, located in the 12th floor of Toronto Rehabilitation Institute, which consisted of a furnished bedroom, living room, bathroom and kitchen. This lab resembled a typical single-story house with functioning wiring and plumbing,
similar to the ones in which homecare workers and family caregivers perform care tasks. The same member of our research team performed the role of patient actor in all trials (a 24-year-old female, 179 cm in height and 83 kg in mass). A wheelchair (category 3, 18”x18” NRG+, Maple Leaf Wheelchair Mfg Inc., Mississauga, ON) with adjustable armrests, working push brakes and swing out standard footrests was used in this study. Figure 30 shows the setting used for this study.

![Figure 30. Setup of HomeLab for this study](image)

8.1.2 Instrumentation

PostureCoach v0.2 was used for this study. The microcontroller in PostureCoach was programmed to provide feedback to the participant when pre-set relative angle thresholds for forward bending were exceeded, while saving this angle data to an SD card at 20Hz. This feedback provided to the participants took the form of audible tones. Threshold angle for providing feedback was customized for each participant, based on their baseline performance. After the baseline trial, a MATLAB script was used to
analyze the data collected by PostureCoach to calculate a personalized threshold. This threshold was set to 10 degrees less than each individual’s 90th percentile spine flexion angle during the baseline trial. However, this threshold was not allowed to be less than 20 or more than 45 degrees. For example, if a person’s 90th percentile angle value was larger than 45 degrees, the threshold of PostureCoach’s feedback was set at 45 degrees. These partially customized threshold limits were selected to avoid over-prompting, which we felt could discourage adoption of the system. Instead, the prompts were designed to avoid prompting participants who are already performing well at baseline, and to gently shift participants who spend more time in near end-of-range spine flexion.

Four webcams were installed in HomeLab to collect video of all data collection sessions, in order to segment the kinematic data by activity and for identifying any potential problems during data collection, including but not limited to interruptions. Figure 30 shows the setup of this study from webcam’s perspective.

8.1.3 Participants

In order to represent novice family caregivers, a convenience sample of 11 healthy adults with no formal training in caregiving or patient handling were recruited for this study. Participants were randomly assigned to the experimental group (n=9) or control group (n=2). Table 3 describes our participants. All were over the age of 18, and could speak and understand English. They had no formal education in caregiving or patient handling. They had no self-reported history of back pain in the last six months or musculoskeletal issues related to the spine.
Table 2. Demographic information of participants included in data analysis. Mean ± SD values are reported, where applicable.

<table>
<thead>
<tr>
<th></th>
<th>Control (n=2)</th>
<th>Intervention (n=9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>23 ± 0</td>
<td>23.8 ± 3.8</td>
</tr>
<tr>
<td>Sex</td>
<td>1 female; 1 male</td>
<td>5 female; 4 male</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>177.0 ± 6.0</td>
<td>176.2 ± 9.2</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>83.5 ± 1.5</td>
<td>66.5 ± 8.4</td>
</tr>
</tbody>
</table>

The small number of control participants was selected to assess the potential change in novice caregiver spine flexion due to a learning effect, which our pilot testing indicated was small, relative to the feedback effect attained by the use of PostureCoach.

8.1.4 Protocol

Figure 31 shows a summary of the two-day protocol for participants in the control (left side) and intervention (right side) groups. A member of our research team greeted each participant upon arrival on day one of this protocol at HomeLab.

![Figure 31. Schematic of the protocol used for pilot study with control group shown on the left and intervention participants on the right](image-url)
**Day One** - At the beginning of the first session and after obtaining written consent, the researcher walked the participant through a typical series of simulated caregiving tasks and answered any questions the participant had. The list of simulated care tasks performed (in order) by each participant was:

- Wheeiling the wheelchair from living room to bedroom
- Transferring the patient from the bed to the wheelchair
- Wheeiling the patient to living room and placing the wheelchair near couch
- Transferring the patient to the couch
- Transferring the patient from the couch to wheelchair
- Wheeiling the patient from living room to bathroom
- Helping the patient to stand, doff his/her pants, and sit on the toilet
- Helping the patient to stand, don his/her pants, and sit on the wheelchair
- Wheeiling the patient back to bedroom and preparing the bed
- Transferring the patient from wheelchair to bed
- Moving wheelchair back to living room

A hardcopy list of these tasks with short descriptions was provided to each participant (Appendix A: List of Care Activities).

Following the introduction to the set of care tasks, each participant was asked to don the PostureCoach v0.2 system and perform the care tasks to measure *pre-video (Trial 1)* performance (PostureCoach’s feedback feature was turned off for this trial for all participants), followed by an initial knowledge test on back injury prevention (Appendix
B: Back Injury Prevention Video Questionnaire). Then a training video with information about safe patient handling strategies was played for all participants (Video Here: https://youtu.be/vtDGheJlfh4), before asking them to again answer the test with multiple-choice questions to measure knowledge transfer on topics covered in the video (Appendix B). The video used for training body mechanics and safe patient handling was developed in collaboration with the Occupational Health & Wellness team at Saint Elizabeth Healthcare. The points discussed in the video were adapted from [32, 56, 94].

Following this knowledge test, participants were asked to perform the same simulated care tasks again, to measure baseline performance (Trial 2), (again, PostureCoach’s feedback feature was turned off). Afterwards, participants again performed the caregiving tasks twice more (Trials 3 and 4), but this time the intervention group received real-time feedback from PostureCoach as an audible tone if participants exceeded the spine flexion threshold described above, while the control group did not receive any feedback. Participants were asked to attempt a toe touch at certain points in the series of simulated care activities to track changes in spine flexion ability over all four trails and to help with segmenting data.

Day Two - On the next day, participants started by performing the same simulated care activities without feedback, to measure baseline performance (Trial 5) on Day Two. Afterwards participants repeated the care activities again two more times, but with feedback turned on (Trials 6 and 7) for the intervention group and feedback turned off
for those in the control group. After a short break, they again performed the care tasks, without feedback for both groups (Trial 8).

8.1.5 Data Analysis

The spine flexion angle data was normalized by calculating the median maximum forward flexion value for all toe-touch trials for each participant. This allowed for expressing each participants’ data as a percentage of their maximum spine flexion. This normalization helped to eliminate the differences in forward flexion angles measured that were due to variations in sensor placement, as well as account for differences between participants’ height and flexibility.

Next, the data was trimmed by removing the toe-touching tasks and the remaining data was used to find the histogram for spine flexion angles in each trial and calculate the 50th, 80th and 95th percentiles of spine flexion. These three percentiles are used for quantifying the distribution of spine flexion histogram.

Independent t-tests were used to compare 50th, 80th and 95th percentiles of spine flexion between control and intervention groups in Trial 8. As participants were randomly assigned to each group, a significant difference between groups at the end of study (Trial 8) can be attributed to the use of PostureCoach.

8.2 Results

A sample of lumbar spine flexion measured using PostureCoach in this study is shown in Figure 32.
Figure 32. Sample of lumbar spine flexion data measured for a single participant using PostureCoach. The red dashed-line represent the angle between the sensors when participant is standing straight, and is used as the zero for forward flexion in this case.

For the intervention group, the data from all participants was used to plot a histogram of forward spine flexion for trials 1, 2 and 8 as shown in Figure 33 (recall that no feedback was given during these three trials).

![Histogram](image)

Figure 33. Average histogram of forward spine flexion in intervention group for Trial 1, Trial 2 and Trial 8 trials along with corresponding 95% confidence intervals

We compared between the control and intervention groups to estimate how much of the changes we saw were due to participants repeating the activities multiple times
(repetition effect) and how much of the change could be attributed to feedback from PostureCoach (PostureCoach effect). To compare between control and intervention groups, the 50th, 80th, and 95th percentile of forward flexion angle in each trial was calculated. These values are shown in Figure 34.

*Figure 34. 50th, 80th and 95th percentile values for normalized forward flexion for the intervention and control groups. The error bars represent standard error.*
Independent t-test revealed that the 80th and 95th percentile of forward flexion in Trial 8 among individuals in intervention group ($M_{80th} = 42.7, SE_{80th} = 3.33$ and $M_{95th} = 57.1, SE_{95th} = 3.36$) is significantly less than the control group ($M_{80th} = 55.3, SE_{80th} = 1.55$ and $M_{95th} = 85.0, SE_{95th} = 0.80$), with $p = .05$ and $p = .003$ respectively. This difference could not be observed ($p = .35$) in 50th percentile of flexion ($M_{ctrl.} = 19.9, SE_{ctrl.} = 2.00$ and $M_{interv.} = 24.97, SE_{interv.} = 2.30$).

These statistical tests were only done as an exploratory exercise since the control group sample size is small. Still, the relatively large effect sizes ($Cohen's d = 1.49$ and 2.93 respectively) are an important positive indication [95].

### 8.3 Discussion

There were two groups in this study. Participants in intervention group watched a training video and received realtime feedback from PotureCoach, while the ones in control group only watched the video. These results indicate that while there were no differences between the two groups at the beginning of study (Trial 1), there were statistically significant differences at the end (Trial 8). The histogram in Figure 33 demonstrates that the individuals in intervention group showed a reduction in time spent in end-of-range spine flexion over the two-day training period. These findings suggest that participants had shifted their behavior to safer movement patterns over the duration of the study. However, it is possible that some of this change in behavior was the result of the repetition effect resulting from repeating the same care activities eight times over two days.
Figure 34 show that while 50\textsuperscript{th} percentile of forward flexion remains the same between groups, the value of 80\textsuperscript{th} and 95\textsuperscript{th} percentile of flexion decrease in intervention group much more than control group as the study goes forward. The histogram in Figure 33 agrees with these results since it shows a shift to the left and toward median values when we compare \textit{Trial 1} to \textit{Trail 8}.

These results indicated that participants in intervention group using PostureCoach utilized lower amounts of spine flexion for performing care activities after a two-day training period. This reveals that a wearable device with real-time feedback based on posture can be effective for quickly reducing the risk of back injury among novice individuals. Therefore, PostureCoach has the potential to be integrated into a training program for caregivers, including but not limited to personal support workers as well as informal caregivers.

8.4 Lessons Learned from this Pilot Study

There were a number of findings from the pilot study that led to revision of the protocol for the full study described in chapter 9:

- We noted participants found the auditory feedback tone overly jarring and would sometimes jump slightly when the feedback tone was triggered. To make the feedback less jarring, the nature of the feedback was changed so that it would start out as a series of short intermittent tones that increased in frequency as the participant’s spine flexion continued to increase.
intermittent tones turned into a continuous tone when the threshold value was reached.

- The committee suggested the feedback threshold should be based on some percentage of maximum flexion for each participant. A series of pilot tests were done to find a reasonable value, and 70% of maximum flexion was selected as the new feedback threshold.

- The committee felt the study would be improved if we omitted showing the training video to the participants in the control group and this change was reflected in the protocol used in the main study reported in chapter 9.

- Finally, the committee suggested that counterbalancing the order of care tasks in each trial would be beneficial for controlling for order effects and we made this suggested change to the protocol for the main study.
9 Effectiveness of PostureCoach

In this chapter, the main study for this thesis project will be discussed. This study utilizes a revised protocol based on the lessons learned from the pilot study. Modifications to the protocol included:

- The implementation of a series of warning tones in PostureCoach’s audio feedback that gradually increase in frequency the as the user approaches the spine flexion threshold. These separate tones replace the sudden onset of a continuous tone that participants in the pilot study found jarring.
- The feedback threshold was changed from a performance-based value to an anatomical-based system that was to each participant’s 70 percent of maximum spine flexion value.
- The order of tasks between trials was counterbalanced to minimize order effects.
- The training video was not shown to the control group between Trial 1 and 2 of control group to better capture the repetition effect.

9.1 Methods

9.1.1 Setting

This study took place in HomeLab, located on the 12th floor of Toronto Rehabilitation Institute, which consisted of a furnished bedroom, living room, bathroom and kitchen.
This space resembled a typical single-story house with functioning wiring and plumbing, similar to homes where family caregivers would perform daily care activities.

9.1.2 Instrumentation

PostureCoach v0.2 was used in this study and had the ability to produce a continuous audible tone based on the spine flexion threshold angle equal to 70% of each participant’s maximum forward flexion angle at baseline (70% max). A second threshold was set to the spine flexion angle equal to 20° less than the 70% max value, which was used to provide intermittent tones that increased in frequency up to the 70% max threshold at which point the sound became a continuous tone. PostureCoach collected data at 20Hz.

9.1.3 Participants

Fourteen healthy adults between the ages of 21 and 41 were recruited for this study (see Table 3). All participants were over the age of 18, and could speak and understand English. They had no history of back pain in the past six months and had no musculoskeletal issues related to the spine. Participants were counterbalanced between the intervention group (n=10) and control group (n=6) based on height and age.

*Table 3. Demographic information of participants included in data analysis. Mean ± SD values are reported, where applicable.*

<table>
<thead>
<tr>
<th></th>
<th>Control (n=6)</th>
<th>Intervention (n=10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>25.8 ± 1.6</td>
<td>28.1 ± 6.4</td>
</tr>
<tr>
<td>Sex</td>
<td>5 female; 1 male</td>
<td>4 female; 6 male</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>172.3 ± 9.9</td>
<td>171.6 ± 7.2</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>62.2 ± 8.7</td>
<td>71.3 ± 16.3</td>
</tr>
</tbody>
</table>
The same member of the research team (a 24-year-old female, 179cm in height and 83kg in weight) played the role of patient actor for all participants.

9.1.4 Protocol

The protocol listed above is similar to the pilot study described in chapter 8 except that the individuals in control group did not watch the training video and simply repeated the same set of simulated care activities four times on each day, with the order of tasks counterbalanced to avoid order effects. This change to the study design is reflected in Figure 35.

![Figure 35. Schematic of the updated protocol used in this study](image)

9.1.5 Data Analysis

The spine flexion angle data was normalized by calculating the median maximum forward flexion value for all toe-touch trials for each participant. This allowed for expressing each participants’ data as a percentage of their maximum spine flexion. This normalization helped to eliminate the differences in forward flexion angles measured...
that were due to variations in sensor placement, as well as account for differences between participants’ height and flexibility.

Next, the data was trimmed by removing the toe-touching tasks and the remaining data was used to find the histogram for spine flexion angles in each trial and calculate the 50th, 80th and 95th percentiles of spine flexion.

A mixed designed analysis of variance (ANOVA) with one between subject variable (control or intervention groups) and one within subject variable of trial number (Trial 1, Trial 2, Trial 5, Trial 8) was used to investigate the differences between groups. The chosen trials did not have feedback provided in either group, and were therefore comparable.

Bonferroni Post-hoc tests were used to investigate difference in the 50th, 80th and 95th percentiles of spine flexion between Trial 1 and Trial 2 (video effect) as well as Trial 1 and Trial 8 (program effect) in intervention group.

Independent t-tests were used for comparing measures of distribution (percentiles) between groups, in Trial 1 and Trial 8.

A repeated measures analysis of variance with within subject variable of trial number (Trial 1 through Trial 8) was used for investigating the significance of changes in percentiles of spine flexion in the control group (repetition effect).
9.2 Results

Figure 36 shows the histogram of the lumbar spine flexion angle (in degrees) for the intervention group in Trials 1, 2, and 8. Recall that Trial 1 and Trial 2 are before and after watching training video, and Trial 8 is final trial for each participant. None of the participants received auditory feedback from PostureCoach in any of these trials.

![Histogram of lumbar spine flexion angles](image)

*Figure 36. Average histogram of forward spine flexion angles (in degrees) in intervention group for Trial 1, Trial 2 and Trial 8 along with corresponding 95% confidence intervals*

After normalizing spine flexion angles based on maximum flexion values, the 50th, 80th and 95th percentile values of spine flexion for control and intervention group are shown in Figure 37. Recall that individuals in control group do not watch the training video, contrary to the pilot study.
Mauchly’s test of sphericity showed no violations of sphericity in any of the measures (percentiles) for the mixed ANOVA. There was a significant main effect of trial number across all three measures, with $F(3,36) = 4.471, p = .009, \eta_p^2 = .271$, $F(3,36) = 6.181, p = .002, \eta_p^2 = .340$, and $F(3,36) = 6.267, p = .002, \eta_p^2 = .343$ for 50th, 80th and 95th percentile, respectively.
Moreover, there was also an interaction effect between trial and group for 80th and 95th percentile of forward flexion, with $F(3,36) = 8.154, p < .0005, \eta^2_p = .405$, and $F(3,36) = 8.643, p < .0005, \eta^2_p = .419$ respectively.

Post-hoc tests (Bonferroni) revealed that while there are no significant differences in the 50th or 80th percentile of forward flexion values between trials 1 and 2 for individuals in intervention group, there was a significant difference in the 95th percentile value of flexion ($p = .05$) (video effect). Post-hoc tests also revealed that the 80th and 95th percentile forward flexion values in Trial 1 were significantly higher than Trial 8 among intervention group ($p = .024$ and $p = .002$, respectively), while they remain constant for control group (program effect).

**Figure 38.** Video effect among individuals in intervention group. Error bars show standard error.

**Figure 39.** Overview of program and repetition effects. The left bar in each group of each graph corresponds to the Trial 1 and the right one to the Trial 8. Error bars show standard error.
9.3 Discussion

The results of this study revealed that the amount of end-of-range spine flexion utilized by the intervention group was reduced as a result of the training program while it remained unchanged in the control group.

Again, the histogram in Figure 36 demonstrates that the individuals in intervention group gradually improved by spending less time in end-of-range spine flexion over the two-day training period. This suggests that participants in the intervention group shifted their behavior to safer movement patterns as a result of the training program (program effect). The performance of individuals in the control group rejects the possibility that these changes in behavior were the result of the repetition effect arising from simply repeating the same care activities eight times over two days. These effects are presented in Figure 37.

Figure 37 also shows that while 50th percentile of forward flexion remained statistically unchanged in both groups between trials 1 and 8, the value of 80th and 95th percentile flexion values decreased in the intervention group but not in the control group.

The results also indicate that watching the video only affected the 95th percentile forward flexion values in participants in the intervention group while 50th and 80th percentile values remained the same between the Trial 1 and Trial 2.

The findings of this study shows that even a brief training video, much like a traditional lectured-based training program, can affect a short-term reduction in the amount of
extreme flexion used for performing caregiving tasks. However, when this training program is integrated with real-time posture-based feedback practice sessions, the shift in participants’ performance (in terms of utilizing less end-of-range spine flexion) is greater and may have longer retention. However, repeating a same set of tasks over time does not significantly alter performance in the time period of the proposed training program.
10 Effectiveness of the Training Video

A questionnaire (Appendix B: Back Injury Prevention Video Questionnaire) was used to determine the knowledge of participants about spine mechanics and preventing back injury. This questionnaire was administered before and after watching the training video to determine video’s ability in transferring the key points about back injury prevention to the individuals, based on the difference between the test results.

Test scores on the back injury prevention questionnaire improved or remained the same among every single participant after watching the training video (Figure 40). A paired t-test revealed that the improvement in average test score, from 8 ± 1.6 before watching the video to 9.4 ± 0.8 was statistically significant ($p < .0005$). Note that both groups watched the video in the pilot study, while only the intervention group did so in the main study.

Moreover, there was an increase in self-reported perceived knowledge on back injury prevention and lifting techniques from before (0.37 ± 0.10 and 0.41 ± 0.12)
respectively) to after (0.57 ± 0.19 and 0.52 ± 0.10 respectively) training video. Both
difference in back injury prevention ($p = 0.04$) or lifting technique knowledge ($p = 0.03$) were statistically significant. Again, both groups of the pilot study and the
intervention group of main study were included in this analysis.
11 General Discussion

The main study on effectiveness of PostureCoach v0.2 (Chapter 9) revealed that a training program consisted of an educational video and real-time posture-based feedback, can reduce the end-of-range spine flexion. Specifically, the 80th and 95th percentile forward flexion values in intervention group show reductions of 36.0% and 29.1%, respectively.

The findings of this study are difficult to compare to past work reported in the literature since outcome measures are different. One of the few comparable studies showed that qualitative real-time verbal knowledge-of-performance feedback over a one-hour-long box lifting training program resulted in an immediate post-training reduction in “peak” spine flexion angle of 51.3%, and a reduction of 31.8% one-week later [96]. Though it may be important to note that the training provided in this box lifting study attempted to get participants to avoid all spine flexion while ours focused on reducing only end-of-range flexion. With this in mind, our results seem to be in line with the box lifting study.

Kernozek et al. reported that real-time performance-based auditory feedback reduce the average maximum forward flexion moment 43.4%, over six weeks of training [71]. Real-time auditory and visual biofeedback from LiftTrainer causes a 5.0% reduction in average forward flexion bending moment [76]. Orthosense, a wearable device that provides real-time auditory and vibration feedback based on spine flexion was activated 52.3% fewer times, and for 63.9% shorter durations after three biofeedback trials [80]. A single accelerometer-based real-time biofeedback system decreased the time spent in
unsafe neck postures 82% over a 5-hour period [78]. The reported comparisons for all of the aforementioned studies are between baseline and retention trials, in which feedback is absent, the same with our study.
12 Conclusions

My findings indicate that the training program evaluated in this work has the potential to reduce the risk of back injury for caregivers. The program resulted in a clear shift in behaviour with novice caregivers spending less time in end-of-range spine flexion while performing simulated care tasks compared to control participants.

The key findings of this work are summarized below:

**C1:** PostureCoach v0.2 showed an improved accuracy over PostureCoach v0.1 in determining spine flexion angles when compared with Vicon motion capture system as the gold standard.

- **C1.1:** The accuracy of PostureCoach v0.2 for tracking spine flexion in the lab setting was 2.0° (RMS Error) and $r = .998$ (Pearson correlation coefficient) when compared with the Vicon motion capture system.
- **C1.2:** The accuracy of PostureCoach v.2 for tracking spine flexion in simulated home setting was 2.3° (RMS Error) and $r = .986$ (Pearson correlation coefficient) when compared with the Vicon motion capture system.

**C2:** A back injury prevention training program, consisting of an educational video about safe patient handling and spine biomechanics, and real-time auditory feedback from PostureCoach, significantly decreases the 80th and 95th percentile values of spine flexion angles (36.0% and 29.1% reduction,
respectively) when performing a series of care tasks, among novice caregivers (program effect).

**C3:** The back injury prevention training video that included information about spine biomechanics and basics of safe patient handling had a significant effect on reducing the 95th percentile of spine flexion (8.0% reduction) when performing a series of care tasks for novice caregivers (video effect).

**C4:** Repeating a series of care tasks eight times did not have a significant effect on the 50th, 80th and 95th percentile of distribution of spine flexion angles for novice caregivers (repetition effect).
13 Future Work

Below, I have summarized the next steps that I suggest be taken in order realize the potential of this promising work. I have divided these next steps into short term and long term tasks:

13.1 Short Term

- Determine how long the reduction of end-of-range spine flexion is retained by PostureCoach users as a result of the current training program. This can be done efficiently by performing a follow-up study with some of the individuals in intervention group in my final study.

- Evaluate the current training program with real-world family caregivers and personal support workers (n=20) to reduce end-of-range spine flexion.

- Implement faded (reduced feedback frequency over time) feedback in PostureCoach and assess its impact on long-term retention of postural improvement.

- Determine the effect of feedback from PostureCoach on risk of injury to parts of body other than the spine.

13.2 Long Term

- Perform a largescale study on the effectiveness of PostureCoach in reducing the risk of back pain/injury for family caregivers and personal support workers using a fading feedback protocol in a training program and assess its impact on long-term retention of postural improvement.
• Commercialize PostureCoach so it can be used as a training tool for different healthcare workers and family caregivers.
14 References


86. UPRIGHT. *UPRIGHT GO.* 2017; Available from: https://www.uprightpose.com/products/.


90. LLC, P.T. *Prana Tech.* 2014; Available from: http://prana.co/.


96. Chan, V.C.-H., *Comparing Augmented Feedback and Didactic Approaches to Reduce Spine Motion During Box and Paramedic Lifting Tasks: A Laboratory-Based Motor Learning Study,* in *Department of Exercise Sciences.* 2018, University of Toronto.
Appendix A: List of Care Activities

You will be asked to perform the following activities, in this order, during each trial. A researcher will lead you through each of the activities listed below:

<table>
<thead>
<tr>
<th>Activity</th>
<th>Steps for Transferring out of Wheelchair</th>
<th>Steps for Transferring into Wheelchair</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stand Straight - Do a toe touch</td>
<td>• Ensure both brakes are engaged</td>
<td>• Ensure both brakes are engaged</td>
</tr>
<tr>
<td></td>
<td>• Take patient’s feet off of footrests and move footrests out of the way</td>
<td>• Move footrests out of the way</td>
</tr>
<tr>
<td></td>
<td>• Retract the armrest on the side of the transfer</td>
<td>• Retract the armrest</td>
</tr>
<tr>
<td>Transfer wheelchair from living room to near bed and adjust footrests</td>
<td></td>
<td>• Return footrests and armrest to original state after finishing the transfer</td>
</tr>
<tr>
<td>Transfer patient from bed to wheelchair</td>
<td></td>
<td>• Do not forget to disengage the brakes before moving the wheelchair</td>
</tr>
<tr>
<td>Wheel patient to living room and place wheelchair next to couch</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transfer patient to the couch</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stand Straight - Do a toe touch</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transfer patient from the couch to wheelchair</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wheel patient from living room to bathroom</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Help patient to stand, doff his/her pants, and sit on toilet</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stand Straight - Do a toe touch</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Help patient to stand, don his/her pants, and sit on wheelchair</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wheel patient back to bedroom and prepare the bed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transfer patient from wheelchair to bed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjust wheelchair’s footrests, and move back to living room</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stand Straight - Do a toe touch</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix B: Back Injury Prevention Video Questionnaire

Have you watched our back injury prevention video yet? (Please circle)  Yes  No

How knowledgeable are you in the following areas?

(Please place a mark on the lines below to rate your knowledge)

<table>
<thead>
<tr>
<th>I have no knowledge</th>
<th>I am an expert</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spine anatomy</td>
<td></td>
</tr>
<tr>
<td>Back injury prevention</td>
<td></td>
</tr>
<tr>
<td>Lifting techniques</td>
<td></td>
</tr>
</tbody>
</table>

Choose the answer that is most correct:

1. Which statement(s) is/are true regarding back pain/injury?
   a. It is important to prevent back injuries because fully healing them can be difficult
   b. Pain from a back injury usually goes away and never comes back
   c. You are not at risk of back injury if you are in good shape
   d. Both b and c

2. Most back injuries are the result of:
   a. Single events that overload the spine resulting from supporting too much weight
      (attempting to catch a falling patient)
   b. Single events that overload the spine resulting from awkward postures (bending and/or
      twisting)
   c. Small amounts of damage to the spine that accumulate over time resulting from
      supporting too much weight or using awkward postures
   d. Both a and b

3. To prevent back pain/injury when lifting someone, it is best to:
   a. Avoid bending, keeping your upper body upright
   b. Keep the object you are lifting as close to your body as possible
   c. Limit the amount of weight you are lifting to 35lbs
   d. All of the above

4. It is best to stay upright while keeping the object you are lifting close to your body because:
   a. Your low back muscles will have to contract less in order to balance the weight of upper
      body
   b. Your low back muscles will have to contract less in order to balance the weight of the
      object
   c. it is not important
   d. a and b

5. Sometimes, it is impossible to provide the necessary care without bending. If bending is needed, it is
   best to:
   a. Flex your spine
   b. Bend from the hips
   c. Flex your spine while bending your knees
   d. a and b
6. What is the most you should lift when you are involved with patient handling?
   a) 750 lbs.
   b) 35 lbs.
   c) 100 lbs.
   d) 75 lbs.

7. Which of the following approaches reduces the risk of back injury?
   a) Stick your bum out (this helps you bend from the hips)
   b) Keep your arms extended
   c) Flex you spine
   d) Both b and c

8. Which of the following approaches does NOT reduce the risk of back injury during patient care?
   a. Adjusting the settings, e.g. bed height
   b. Keeping the load close to body
   c. Limit the amount of weight lifted
   d. Keeping your elbows bent at all times

9. What is the best way to position the spine when bending to reduce the risk of injury and why?
   a) Keep the natural curve in the spine. This allows the boney parts of spine to share the load with the intervertebral discs.
   b) Keep the spine flexed. This allows the boney parts of spine to share the load with the intervertebral discs.
   c) Keep the natural curve in the spine. This allows the intervertebral discs to take all the weight.
   d) Keep the spine flexed. This allows the intervertebral discs to support the full load on the spine.

10. Who is at the least risk of a back injury?
    a. 
    b. 
    c. 
    d. 

Appendix C: Script of Back Injury Prevention Video

Every day, healthcare workers like you, perform a variety of tasks such as toileting, bathing, and transferring patients. These activities usually require bending and twisting in awkward ways while supporting heavy loads. All of these things put you at risk of developing a back injury.

Back Injuries are the most common type of injury experienced by home healthcare workers. The bad thing about back injuries is that they not only affect your work, but can stop you from doing the things you enjoy in your everyday life. Modern medicine does not always have the ability to heal a back injury, and that is why prevention is key. Here is a look at how a back injury has impacted a caregiver like you:

“Pain never really goes away. I live with discomfort almost every day. Sometimes it’s worse that other times. It’s such stressful physical ... and emotional state.”

As you can see, it is extremely important to take the right steps to lower your risk, and prevent back injuries. If you are new to caregiving, now is the time to stop an injury before it begins. There are a number of strategies to decrease your risk. Throughout this video we will highlight these five key points to remember when on the job.

a) Prevention is key
b) Keep the load close to your body
c) Limit what you lift
d) Avoid bending
e) Hinge at the hip

One of the main reasons why prevention is so important is because back injuries are nearly impossible to fully heal. Let’s take a closer look at the anatomy to be able to understand how back injuries happen and why a full recovery is difficult.

The spine is made up of alternating vertebrae and discs. The vertebrae are bones so they are hard and rigid, while the discs are made up of a fibrous material making them flexible to allow for movement and bending of the spine. However, this means the discs are more susceptible to injury.

When the back experiences high forces from lifting, over time, the discs will become damaged and degenerate. You can’t always feel the damage right away, so the injuries continue to get worse without you realizing.

Another important anatomical feature of the spine are the nerves, which exit the spinal column through openings between the vertebrae. When your discs degenerate, the nerves get pinched, causing a lot of pain.

Unlike most parts of the body, discs don’t have a blood supply. Instead they rely on the flow of fluid to get nutrients and get rid of waste to stay healthy. By the time people start to feel pain, back injuries are severe and very difficult to heal. Because of this, prevention is the most important thing you can do to keep your back healthy.
The spine is very strong and can support over 750 lbs on average. 750lbs may sound like a lot but that weight includes the object you are lifting, your upper body weight, and the counterbalancing forces your muscles need to generate to keep you from falling over.

A big factor in back injury prevention is how far away from your body you hold the object. When lifting an object, your body acts like a lopsided teeter-totter that has to stay balanced to stop you from falling. On one side you have the weight of what you’re lifting, plus the weight of your upper body, each of which are multiplied by the distance they are from your back. On the other side of the teeter-totter you have the forces from the muscles on the spine, which generate what is needed to stay balanced. As you can see, a small amount of weight, even just 20 lbs, results in huge forces on your back. On the other hand, bringing the lifted object closer to your body makes a big difference in decreasing that load.

The recommended weight to lift is only 35lbs because caregiving activities often require bending, twisting, reaching, or other awkward postures. Whenever possible, it is recommended to use equipment such as lifts, or get help from another person if you are moving heavier loads.

Bending and twisting also increase those forces so it is best to avoid both movements whenever possible. One way to decrease bending is to adjust the patient’s bed before performing a lift or transfer and twisting can be reduced by moving your feet to put yourself in a favourable position. It may seem like a waste of time to raise the bed by a couple inches or take a couple steps, but it could save you from a back injury.
Completely avoiding bending and twisting is almost impossible when performing caregiving activities, but you can help protect your back by using the proper technique.

Let’s go back to the anatomy of the spine to see how posture affects disc damage. When you’re standing up, your back is never fully straight, and you don’t want it to be fully straight. That natural curvature allows the bony joints on the back of the vertebrae, called facet joints, to connect and support the majority of the weight. When the back is in its curved state, there is minimal force directly on the discs which means healthy discs.

Unfortunately, when most people bend, they flex their back, and that natural curvature in the lower back is lost. This puts all the pressure on the discs and leads to the disc degeneration that we discussed before.

The better way to bend is to keep the natural curve of the spine and bend at the hips instead. This means sticking your bum out, bending the legs, and tilting your pelvis forward. If you think of your pelvis as a water bucket, you want to pour the water out the front, which allows you to keep your lower back in its natural, curved shape while bending forward. To practice this technique, first start by standing up straight and placing your hands on the front of your thighs, next stick your bum out and slide your hands down to your knees while hinging your hips. You know you are doing it right if you are able to keep your chest out in a “proud chest” position, and your shoulders are not rounded downwards. The hip hinge technique allows the facet joints to support most of the weight, which reduces risk of back injury.
And that’s it. The 5 key points to take away from this video are:

1. Prevention is key
2. Keep the load close to your body
3. Limit what you lift
4. Avoid bending
5. Hinge at the hip

By remembering these, you can greatly reduce your risk of back injury. Being aware of your posture and lifting technique goes a long way.
Appendix D: Forward Flexion Measured by PostureCoach vs Vicon

Figure 41. Forward flexion measure by PostureCoach compared to Vicon for Participant #1.

Figure 42. Forward flexion measure by PostureCoach compared to Vicon for Participant #2.
Figure 43. Forward flexion measure by PostureCoach compared to Vicon for Participant #3.

Figure 44. Forward flexion measure by PostureCoach compared to Vicon for Participant #4.
Figure 45. Forward flexion measure by PostureCoach compared to Vicon for Participant #5.

Figure 46. Forward flexion measure by PostureCoach compared to Vicon for Participant #6.
Figure 47. Forward flexion measure by PostureCoach compared to Vicon for Participant #7.

Figure 48. Forward flexion measure by PostureCoach compared to Vicon for Participant #8.