Characterizing the Biomechanical Exposures Associated with Common and High Demand Personal Support Worker Tasks

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Background:

The physical demands that personal support workers (PSWs) are exposed to are increasing as our population ages and our society is increasingly shifting to at-home care, resulting in increases in workload demands. However, PSWs are also developing high rates of musculoskeletal disorders (MSD) likely because of increased exposure to physical task demands. There is a need to intervene to protect these essential healthcare workers. Presently, little is known about the biomechanical exposure characteristics associated with PSW work tasks, especially within a home care setting. PSW work is highly dynamic and a wide range of tasks with different loading scenarios are completed. This means that the time-series exposure patterns are also likely varied over a work shift or work week, where this variation may be important when designing effective ergonomic interventions. As an example intervention strategy, workload management may be an effective approach to monitor, assess, and redistribute workload as needed to provide recovery windows to reduce and mitigate the accumulation of exposure. Real-time tracking and the continuous monitoring of PSW exposures, or surrogates, may assist in the assessment of injury risk.

To better understand the biomechanical exposure characteristics associated with common PSW work tasks and to explore the potential utility of ratings of perceived exertion (RPE) as a potential surrogate measure to track PSW workload, this thesis aimed to address the following two objectives and corresponding research questions:

Objectives:

1. Characterize biomechanical exposure metrics associated with the performance of common and highly demanding PSW work tasks.
2. Evaluate the relationship between RPE and the biomechanical exposure metrics.

Research Questions:

1. What are the biomechanical exposures experienced by PSWs when performing simulated common and physically demanding work tasks?
2. What is the relationship between RPE and biomechanical exposure metrics (peak low back flexion angle, peak low back extensor moment, cumulative low back extensor moment) when performing common and physically demanding PSW work tasks?

Methods:

Twenty PSWs were recruited to complete 12 work tasks within a laboratory setting, where full body kinematics and hand forces were collected for all trials. A whole-body top-down rigid link modelling approach was used to calculate biomechanical exposure metrics. Peak low back flexion angle along with

peak and cumulative extensor moments were calculated. Linear regressions tested for relationships between post-task RPE scores and 1) peak low back angles, 2) peak low back extensor moment, and 3) cumulative low back extensor moment at an individual level, where corresponding regression statistics from each participant were the aggregated at the group level.

Results:

Patient handling tasks, such as transfers and repositioning tasks, had the highest peak extensor moments (ranging from 115-157 Nm), while having the lowest cumulative moment values (1329 – 4552 Nm*s). In contrast, patient care tasks such as bathing, dressing/undressing, and compression stocking application, had the highest cumulative extensor moment values (2623 – 8089 Nm*s) and lower peak moments (92 – 107 Nm). Additionally, patient care tasks took the longest to complete and required participants to frequently adopt moderate (20-45 degrees) to severe (>45 degrees) levels of low back flexion.

A significant moderate positive relationship was found between RPE scores and cumulative low back extensor moment ($p<0.05$, $R=0.60$). No significant relationship was found between RPE scores and both peak low back flexion angle ($p<0.05$, $R=0.16$) and peak low back extensor moment ($p<0.05$, $R=-0.13$).

Discussion:

The biomechanical exposure characteristics of PSW work are task dependent. Patient handling tasks subjected PSWs to high peak loads for brief periods of time. Patient care tasks, on the other hand, imposed lower magnitudes of loading for extended time duration. It is well established that low back injury pathways are different when loading is high, but brief, relative to lower in magnitude, but sustained. As such, it appears that groupings of tasks may be of more interest to consider and intervene from the perspective of reducing high peak loads, where others might be better viewed from a cumulative load perspective. Therefore, in the design and development of any effective ergonomic interventions, it may be important to consider task-specific loading profiles and how they may influence injury development based on corresponding pathways. Task characterization as quantified within the current study can serve as a foundation to inform workflow management and patient scheduling decisions in an attempt to optimize temporal aspects of loading.

RPE scores could be used as a surrogate for cumulative low back extensor moment, which may have utility as an easy-to-implement assessment tool to track the accumulation of spine extensor moment loading. These findings can inform additional work to evaluate how real-time RPE tracking functions within real work settings and can explore other metrics that might help to better monitor and track exposures during short duration, high load tasks.

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List of Abbreviations

APDF – Amplitude probability distribution function

CI – Confidence interval

HCA – Health care aide

L5/S1 - 5th lumbar disc/1st level of sacrum

LBP – Low back pain

LPN – Licensed practitioner nurse

LTC – Long-term care

MSD – Musculoskeletal disorder

PSW – Personal support worker

RN – Registered nurse

RPE – Rating of perceived exertion

SD – Standard deviation

1.0. Introduction

Personal support workers (PSWs; also referred to as Health Care Aides, HCAs) provide essential front-line care to patients within long-term care (LTC), assisted living facilities and in the community for those recovering and/or aging at home. In broad terms, PSWs support individuals who require care during recovery or assistance with activities of daily living (ADLs) (HRPAC, 2006; Saari et al., 2017). PSWs represent the largest percentage of the home care sector in Canada, providing nearly 80% of care for residents in LTC facilities (Estabrooks et al., 2014; Hewko et al., 2015; HRPAC, 2006) and 75% of paid home care services in Ontario (Saari et al., 2017). The demands for PSWs are rising as a result of a rapidly aging population and associated shifts to at-home care (Carriére, 2006; Fujisawa and Colombo, 2009; Keefe et al., 2008; Keefe et al., 2011). It is expected that the number of individuals living with chronic conditions will triple between 2010 and 2050 (Prince et al., 2013). That means more individuals will need increasingly complex care, particularly in a home environment (Wowchuk et al., 2006). PSWs will play an important role in helping to meet that increasing demand through the provision of home-based patient care.

An important concern challenging the PSW profession to meet the growing demands for service is musculoskeletal disorders (MSDs). PSWs have higher injury rates than other healthcare workers such as registered nurses (RNs) or licensed practical nurses (LPNs). This supports that PSWs are the most at-risk worker population for sustaining work-related injuries within the healthcare sector (Alamgir et al., 2007; Alamgir et al., 2008). The large majority (>80%) of PSW work-related injuries are musculoskeletal in nature and recent statistics in Canada confirm that PSWs and/or HCAs reported the highest numbers of lost-time claims in 2020, with sprains and strains being a leading source of injury (WSIB Ontario, 2021a, 2021b). Low back injuries are among the most frequently reported, ranging from chronic back pain to acute injuries (Alamgir et al., 2007; Hignett, 1996). High MSD risks coupled with increasing demand is likely to cause even greater MSD challenges in the absence of preventative measures.

The adapting and changing nature of PSW work presents a critical challenge when it comes to designing and implementing ergonomic interventions aimed at mitigating injury risk amongst PSWs. PSWs represent a uniquely unregulated worker population, often required to work in different unconventional care settings and with a range of clients and patients (Hewko et al., 2015; HRPAC, 2006; Wipfli et al., 2012). As a result, PSW work can be highly varied and can be classified as non-repetitive (HRPAC, 2006), with each task's demand constantly changing in terms of intensity, repetition, and duration (Garg et al., 1992; Lim and D'Souza, 2020). By first understanding the biomechanical exposure characteristics of PSW work we can then hypothesize potential injury mechanisms/pathways attributing to increasing injury rates, which in turn can support the design and development of effective ergonomic interventions.

Currently, classic ergonomic assessments/tools typically focus on taking ‘snapshots’ of the work to characterize risks, identify root causes and then ultimately inform the design of interventions (CSA, 2012). The dynamic, non-cyclic and non-unform nature of PSW work renders many classic ergonomic tools of limited use for robustly characterizing PSW work (Lim and D’Souza, 2020; Paquet et al., 2005). Tools and approaches that allow for frequent and live monitoring of PSW demands may provide opportunities for improved surveillance and intervention to preventing and mitigating high rates of injury. One opportunity for intervention may be to leverage strategies from other sectors that aim to reduce the potential for overload/overexposure. Borrowing from athletics, “load management” programs have been implemented to monitor work and recovery periods as a strategy to prevent overexertion injuries (Halson, 2014; Seshadri et al., 2019). Applied to the dynamic work of a PSW, continuous monitoring of work demands, or reasonable surrogates, would be required throughout a PSW’s work shift or even across a work week. However, the ability to monitor relevant metrics in real time poses a significant challenge. First, what measures might be available and practical to capture, and second, how can those measures be used to inform interventions to mitigate injury.

Commonly, monitoring of workload within an occupational setting is executed using instrumentation that can provide direct measurements of physical exposure that are related to MSD risk (Lind et al., 2023). For example, inclinometers have been used to measure bodily posture (Hodder et al., 2010; Holmes et al., 2010; Nourollahi-Darabad et al., 2018) and accelerometers/inertial measurement units to classify tasks as well as posture (Fortin-Coté et al., 2020; Tjøvoll et al., 2022; Schall et al., 2016). Specifically, some devices are able to measure characteristics that are associated with risk factors related to low back pain and injuries, such as bodily postures and internal loads (e.g., joint moments or forces which can be calculated by collecting posture / motion data along with information about external forces acting on the body) (Garg et al., 1992; Yeung, 2012). Methodology involving instrumentation may be suitable for some occupations, but barriers can be encountered if the workers frequently work in varying locations (Halson, 2014). In contrast, subjective measures of exposure have also been extensively used to track and monitor workload within occupational settings. Subjective measures such as Ratings of Perceived Exertion (RPE) or other subjective exertion measures can be collected frequently and easily in most workplace settings and have been found to be acceptable measures to estimate the risk of low back injury (Jang et al., 2007; Yeung, 2012). However, generally, these subjective ratings tend to not have a high-level of fidelity and specificity, providing outputs that are not quite as closely linked to injury risk compared to objective direct measurements. However, little is known about whether RPE might be a useful metric to track and monitor PSW work, or if RPE might share links to biomechanical exposure characteristics that can influence injury through established injury pathways.

Given the identified gaps in the existing literature, there is the need to characterize and quantify the biomechanical exposures associated with PSW work as a precursor to developing effective ergonomic interventions to protect PSWs. Moreover, analysis of the relationship between RPE and biomechanical exposure metrics could inform the foundation for future PSW-targeted ergonomic interventions related the concept of workload management. As such, this thesis aims to characterize and understand the relationship between exposure metrics including RPE, low back flexion motions, and low back extensor moments as PSWs perform a series of simulated common and physically demanding work tasks. Research questions include:

1. What are the biomechanical exposures experienced by PSWs when performing simulated common and physically demanding work tasks?
2. What is the relationship between RPE and biomechanical exposure metrics (peak low back flexion angle, peak low back extensor moment, cumulative low back extensor moment) when performing common and physically demanding PSW work tasks?

Research question 1 is descriptive/exploratory in nature and does not include a hypothesis. However, for research question 2, a moderate relationship is hypothesized between RPE scores and peak flexion, as well as between RPE scores and peak low back extensor moment. For RPE and cumulative low back extensor moments, a strong relationship is hypothesized. Overall, the characterization and calculation of biomechanical exposures experienced by PSWs will allow us to understand how the exposures incurred during completion of tasks affect PSWs and their risk for developing MSDs. As well, if a strong relationship is present between perceived exertion and low back exposure metrics, this could serve as an initial step towards the potential to objectively quantify and continuously track exposure metrics linked with low back MSDs.

2.0. Literature Review

2.1. Current State – The MSD Problem Among PSWs

The role of a PSW is to assist and care for individuals who are limited in their abilities to perform ADLs (HRPAC, 2006; Saari et al., 2017). Common duties performed by PSWs include providing personal care to patients, medication assistance, transferring or repositioning patients and housework (Daly et al., 2012; Hewko et al., 2015; Keefe et al., 2011). However, PSW work is notoriously variable as PSWs are unregulated, work in different care settings and work with a range of patients (Hewko et al., 2015; HRPAC, 2006). As a result, PSW work can vary person-to-person or day-to-day. The dynamic nature of PSW work may explain why there is limited literature available characterizing the biomechanical exposures of PSW work. Work by Alamgir and colleagues concluded that PSWs perform more manual labour tasks, such as patient transfers or lifts, in comparison to LPNs and RNs, which ultimately increase the physical demand of PSW work (Alamgir et al., 2007, Alamgir et al., 2008), but did not explore biomechanical exposures metrics at a more detailed level. As well, it has been extensively documented that patient handling tasks are highly demanding and exposes patient handlers to high-load scenarios (Daynard et al., 2001; Garg et al., 1992; Skotte et al., 2002). In tandem with the physically demanding tasks, the demand for PSWs is rapidly rising as the population continues to age and the average life-span increases (Fujisawa and Colombo, 2009; Keefe et al., 2011). The shift from institutional care (e.g., hospital, LTC) to at-home care further increases the demand for PSWs, who form a large portion of community care, and their associated services (Fujisawa and Colombo, 2009; Saari et al., 2017).

Overall, PSW workload has increased greatly, resulting in rising work-related injury rates. When compared to other healthcare workers such as RNs and LPNs, PSWs have higher injury rates. As of 2020 in Ontario, Canada, PSWs and/or HCAs reported one of the highest numbers of lost-time claims (WSIB Ontario, 2021a, 2021b). In 2007, Alamgir et al. found that 73% of all injuries developed in the community and in nursing home and 60.8% in acute care were categorized as MSDs (Alamgir et al., 2007). Similarly, Ngan et al. (2010) stated that a large portion of MSDs developed amongst care workers are because of patient handling tasks and overexertion. Gohar et al. (2020), who conducted a qualitative study with PSWs, again found that MSDs were a large contributor towards sick leaves amongst PSWs, with repeated and awkward motions being cited as a factor for MSD development. Although more than a decade old, WorkSafeBC (2006) reported that approximately 50% of injuries suffered by home and community health workers were related to repetitive bodily motion and over-exertion injuries, agreeing with findings by Alamgir and Gohar. Around 60% of these MSDs can be attributed to patient handling tasks (Ngan et al., 2010). Among MSDs, sprains and strains are most common (WSIB Ontario, 2021a, 2021b). The low back is the primary location for injury (Alamgir et al., 2007; Hignett, 1996), with chronic back pain being prominent amongst PSWs (Alamgir et al., 2007). Care aides, such as PSWs, are prone to developing low back pain (LBP) due to the nature of their work (e.g., frequent repetitive motion of the trunk), with transfers that can involve forceful lifting movement being the riskiest (Minematsu, 2007). Although the low back is one of the most injured areas amongst PSWs, it is important to acknowledge that injuries to the shoulders and knees are cited frequently as well (Howard and Adams, 2010; Wipfil et al., 2012). Minimal injury data is available for PSWs working in Canada, however, information from the United States provides helpful reference regarding location of injury. Wipfli et al., (2012) found that from 2008 to 2010, amongst PSWs working in home care in Oregan, that low back injuries were the most reported out of the total (~27%), followed by the shoulder (~12%) and the knees (~8%). Similarly, Howard and Adams (2010) found that from 2003-2007, back injuries were claimed the most among PSWs in Washington, followed by the fingers and legs. These data reinforce the importance of focusing on the low back initially as it is the body region that seems to be most affected.

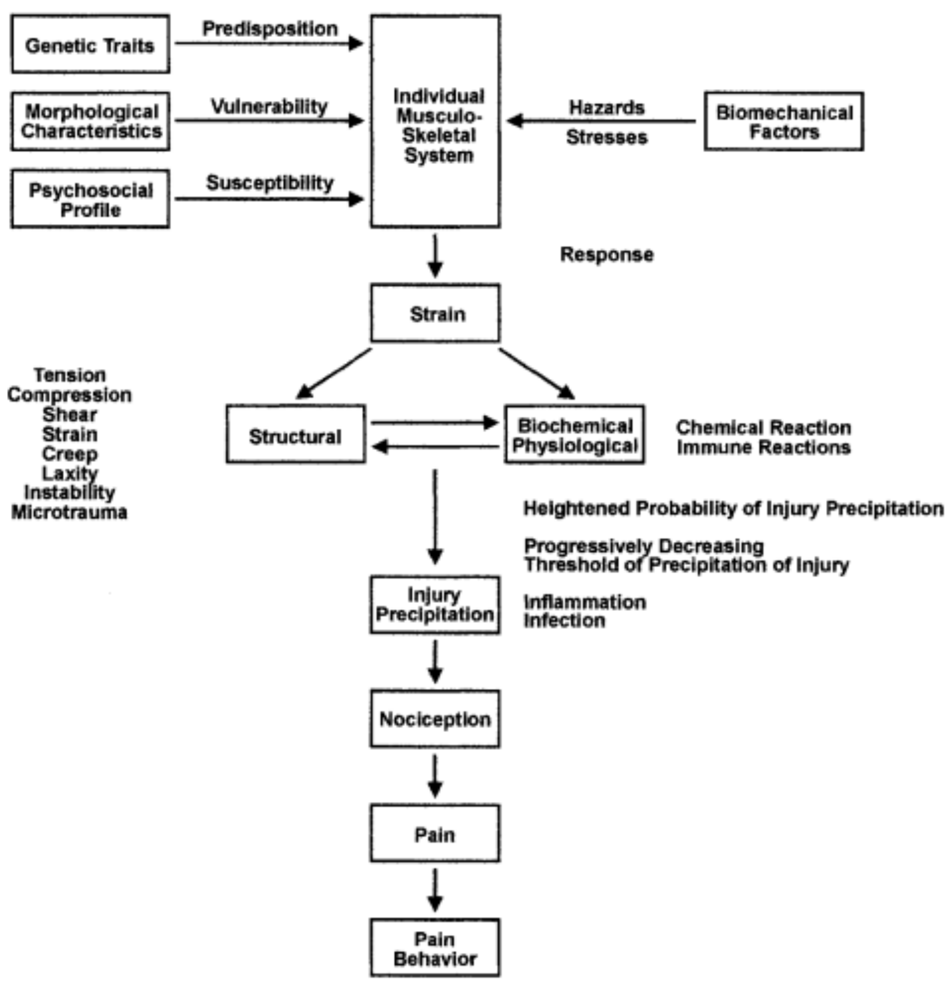
2.2. Current Theories of MSD Causation

2.2.1. Overview on MSD Pathways and Mechanisms of Injury

It is important to consider the numerous different factors that can play a role towards MSD risk when choosing appropriate aspects/exposures to measure and what is meaningful within the context of the target population. As stated in Section 2.1., PSWs largely suffer from sprains and strains as a result of overexertion, which can be credited to a multitude of biomechanical factors. Kumar (2001) presents the Overexertion Theory as an explanation for occupation related MSD development, attributing aspects of the occupation such as force (e.g., external loads, force application), duration, posture and motion causing accumulation of microdamage that ends up exceeding internal tissue tolerance. It is important to note that although these individual factors can largely contribute to higher MSD risk, that the interaction between all these factors must be considered when quantifying risk. To summarize, occupational tasks that require high forces, frequent repetition or sustained application for long durations and are completed in awkward postures significantly increase a workers' risk for MSD development. However, the mechanism/pathway in which the risk is increased can differ depending on the various combination of these biomechanical factors and the different possible weightings, as presented in Kumar's Multivariate Interaction Theory of MSD Precipitation (2001), where these biomechanical directly influence the injury pathway (Figure 1). In addition to the biomechanical factors however, it is necessary to consider the individual's internal tolerance. Defining internal tolerance is more complex than biomechanical exposure. Internal tolerance encompasses many individual-specific factors (e.g., genetics, morphological characteristics, psychosocial profile, mechanical strain, and fatigue tolerance).

With the precipitation of an injury, it can come due to acute or chronic conditions. Acute condition refers to a scenario where an individual is put under high loads during a single event and these forces exceed the tissue's tolerance, leading to injury. This injury mechanism and its effect on worker populations is well researched and documented as being a common injury pathway (McGill, 1997; McGill, 2007). In contrast, chronic conditions refer to a state of fatigued tissues or cumulative fatigue that is more likely to occur from repeated or sustained low to moderate stresses, resulting in reduction of tissue tolerance (Brinckmann et al., 1988; Kumar, 1990; Kumar, 2001; Radwin et al., 2001). However, the combination of these two loading scenarios, which can be common within most healthcare occupations, likely paint a more accurate picture towards why most MSDs occur, which is where sustained loading at low forces without adequate recovery can decrease tissue tolerance consistently, rendering the individual is now more susceptible to injury if forceful exertion is required of them (Kumar, 1990; Kumar, 2001). Therefore, injury mechanisms are dependent on the actions and external factors placed on the individual, and in an occupational context, these are dependent on the workers' tasks. As such, it is pertinent to have a strong understanding of the specific underlying injury mechanisms that may be specific to certain occupations to better direct the development of injury prevention strategies.

Figure 1. *Multivariate Interaction Theory of MSD precipitation (Kumar, 2001).*



2.2.2. Posture

A popular methodology to quantify ergonomic risk is postural analysis. It is well established within literature that awkward trunk postures are a risk factor for LBP (Garg, 1989; Marras et al., 1995; Neumann et al., 2001; Norman et al., 1998; Waters et al., 1993), where these awkward postures (high degree of sagittal flexion and/or extension, asymmetrical postures) can cause localized fatigue and play a role in MSD development (Keyserling et al., 1988). Specifically, regarding low back/trunk angle, a non-neutral posture increases loading and strain in structures such as the spinal discs (e.g., increased compression and shear forces) and increases erector spinae muscles forces required to maintain such postures (Kumar, 2001). Although awkward postures themselves contribute to MSD development, the effects are further exacerbated by other factors such as the duration spent in these postures, the frequency at which these postures are adopted, and if external loads are present (Keyserling et al., 1988; Waters et al., 1993).

Trunk sagittal angle has been found to be a risk factors of low back injury, where high amounts of flexion is linked to increased risk of injury (Marras et al., 2007). Similarly, static postures where the trunk angle is constant for long durations, repetitive bending of the trunk (sagittal or lateral) and twisting of the torso are also associated with the development of LBP and LBD (Marras et al., 2007; Marras & Granata, 1997). For healthcare workers who directly care for patients/clients and perform patient handling tasks, this relationship is very much present (Garg & Owen, 1992; Nourollahi-Darabad et al., 2018; Yeung, 2012). Nourollahi-Darabad et al. (2018) continuously assessed trunk postures adopted by nurses in a hospital ward and found a significant strong relationship between time spent in awkward trunk postures ($\geq 45^{\circ}$ trunk flexion) and LBP ($p<0.05$). Similarly, Yeung (2012) found that awkward sustained back postures were associated with the occurrence of LBP. As such, posture can well inform MSD risk amongst healthcare workers, and therefore for PSWs, and this in combination with the fact the PSWs are frequently adopting awkward postures (King et al., 2019; King et al., 2020), makes posture an important LBP and low back MSD causal factor to consider in ergonomic assessments.

However, postural analysis by itself may not provide be the best approach to predict MSD. Several studies (Gallagher and Heberger, 2012; Wells et al., 2004) stated that although posture is an important risk factors for MSDs, without consideration of a load, the assessment is incomplete. Instead, cumulative load theory (Coenen et al., 2013; Kumar, 1990) and fatigue-failure theory (Gallagher and Schall, 2017) suggest that the accumulation of load on the body, resulting from sustained or repetitive actions, may be better risk factors to consider as posture is inherent in these measures. Therefore, although posture is a simple metric to collect and is recognized to be a strong risk factor and predictor of LBP and low back MSDs, other measures may need to be examined to provide a fuller picture.

2.2.3. Peak and Cumulative Low Back Loads

Prior research regarding LBP and its associated risk factors largely focused on peak spinal loads and it is well documented that there is an association between high loading and LBP (Kumar, 1990; Marras et al., 1993;

Norman et al., 1998). As well, examination of peak loads in a patient handling context has also been well researched, establishing that occupations involving patient handling exposes these workers to high spine loads, translating to high incidence of occupational back injuries (Garg et al., 1992; Jensen et al., 1990; Owen, 1989; Stobbe et al., 1998). Kumar (1990) was among the first to examine cumulative spine loading (force or moment time integral) and its association with back pain amongst patient handling tasks. Kumar identified significantly higher cumulative spine compression and shear in hospital aides with pain in comparison to those without pain, therefore associating cumulative spine load with experienced back pain. Similarly, Norman et al. (1998) established that cumulative biomechanical variables are important risk factors in relation to LBP and Coenen et al. (2012) found that cumulative low back loading is more significant of a factor than factors such as time in a flexed position and number of lifts completed. Cumulative loading variables may better account for the presence of time-dependent changes to biological tissues and their internal tolerance, therefore providing better insight into the risk of MSD development for workers that complete tasks that span longer amounts of time (e.g., during patient transfers) (Santaguida et al., 2005). With time-dependency in mind, it is therefore important to define what 'time' will be used in the calculation of cumulative loads. In the context of patient handling tasks, Santaguida et al. (2005) emphasized the importance of defining duration, for example, when calculating cumulative loads for the period over a single patient handling task, over an entire work shift, or even over a worker's lifetime.

2.3. Relevant Exposure Metrics – Subjective and Objective Measures

2.3.1. Peak and Cumulative Low Back Forces

With the focus on posture, peak and cumulative spine loads as an indicator of MSD risk, it is important to determine what specific measures should be calculated. Tissue loading measures such as low back compression, shear and extensor moment have been used as an indicator of low back load or as a predictor of MSD development. Within research that has quantified measures of spine load amongst PSW or healthcare support workers, mainly spine compression and anterior-posterior shear have been calculated and used as a measure of low back MSD risk.

Kumar et al. (1990) calculated cumulative spine compression and shear amongst hospital nursing aides to compare between subjects that experienced back pain and those who didn't through questionnaires and interviews. Information regarding postures adopted during work tasks and the corresponding loads (e.g., weight of equipment carried) were obtained to calculate cumulative compression and shear experienced by participants who had no LBP and those who had LBP, finding that cumulative compression was higher in the pain group ($p<0.05$). Within their results, there were however, no measures for the specific tasks PSWs completed.

Like Kumar, Holmes et al. (2010) collected postural data using an inclinometer on PSWs working in LTC facilities over working shifts. Observers were used to identify tasks that were being performed, which allowed for the researchers to parse out five levels of patient body weight that was estimated to be supported by the PSW. For example, when the PSW was performing care, an overall 10% of the patient's body weight was assumed to be supported, and when the PSW was repositioning the patient in any manner, 20% of the patient's body weight was assumed to be supported. From there, posture, anthropometrics and estimated weight supported by the PSW were used to calculated cumulative spine compression and shear using rigid-link modelling, single-muscle equivalent assumptions and rectangular integration. Both peak and cumulative L4/L5 compression and shear forces for tasks were calculated, finding that the largest peak forces (compression, lateral and anterior-posterior shear) occurred during single-PSW transfer tasks, with values exceeding NIOSH threshold limits. In contrast, lower peak forces were found for patient care tasks such as bathing, dressing, and feeding the patient. For cumulative loading (for an 8-hour shift), standing and walking accounted for the greatest amount followed closely by patient care tasks which although had low peak forces, were performed most frequently.

Daynard et al. (2001) also examined cumulative spine compression and anterior-posterior shear when analyzing loads during patient handling activities when presenting different ergonomic interventions (e.g., safe lifting policy, 'no-strenuous lifting' system). Participants completed controlled patient handling tasks in the hospital ward they were used to working in while video data was collected. Subsequently, a quasi-dynamic biomechanical computer model was used to calculate cumulative spine loads by replicating the workers' assumed postures when completing tasks and inputting relevant data (e.g., hand loads, anthropometrics). Measures provided were task-specific and cumulative exposures were not calculated across a shift. Daynard and colleagues found that 2-person pivot transfers from bed to wheelchair and chair boosts exposed PSW participants to the greatest peak spine compression, exceeding the NIOSH limits. Therefore, these results surprisingly indicate that patient handling tasks with the use of mechanical devices expose PSWs to greater spine loads in comparison to manual approaches.

Findings from the aforementioned studies share the sentiment that patient transfers (1- or 2- person) resulted in high peak spine forces, while tasks that require long task duration seem to result in higher cumulative loading. This is agreeable with prior identification of patient transfers being a main contributor to low back injuries suffered by PSWs (Garg & Owen, 1992; Marras et al., 1999). However, with these studies being conducted with the workplace (e.g., within facilities, hospitals, etc.), limitations were present when considering the data collected and the subsequent quantification of low back forces. Kumar et al. (1990) relied on the participants to recall the postures they adopted when working and loads they interacted with, which may present many inaccuracies when inputting this data into a biomechanical model to calculate cumulative spine loads. Holmes and Daynard collected inclinometer and video data, respectively, to provide postural data to fuel their biomechanical analysis of low back loading, providing more validity in their quantified exposure metrics. Although the kinematic data collected was not full body, a more complete picture of their participant's motion was captured. With external forces being an important factor influencing any low back loading, Daynard employed force matching during key patient handling actions (e.g., lifts, pulling, pushing) via a hand force dynamometer to obtain hand forces that were used for biomechanical modelling. In contrast, Holmes assumed that a certain percentage of the participant's weight was placed on the participant depending on the type of task, applying the same external load across all participants. This methodology presents the issue of ignoring variability across trials in which the participant is interacting with the patient and makes assumptions on the external forces applied on the participant by the patient. Additionally, the study was conducted with a nursing population, which does not consider the unique context of PSWs and PSW work.

It is understandable that although collecting and analyzing data with worker participants within a real work environment can provide benefits in terms of external validity, limitations are present when considering the internal validity of low back loads calculated due to barriers collecting postural and kinetic data. When reviewing studies that take place within a laboratory setting, Santaguida et al. (2005) calculated cumulative spine compression and anterior shear when comparing loads incurred during patient transfer tasks using different mechanical lift devices. A manual transfer was not performed by participants and was not quantified. Data collection occurred in a laboratory setting, where the participant's body position data was collected using a motion capture system and with the participants standing on force plates throughout the duration of the tasks, providing data for a bottom-up inverse dynamics approach to calculate spine loads. Within a laboratory, a more comprehensive and accurate set of data (e.g., joint angles, posture, external forces, muscle activity) can be collected for the calculation of internal loads, however, there is decreased external validity (e.g., variability that comes with different patient anthropometrics, changes in behaviour within the laboratory).

With a large focus being placed on the quantification of low back compression and shear forces, it is important to note that there are some considerations when performing these calculations. For example, Daynard et al. (2001) used the 4DWATBAK, a quasi-dynamic biomechanical computer model that provides two-dimensional and 3-dimensional link segment models, to calculate both peak and cumulative compression and shear at the L4/L5. 4DWATBAK (Neumann et al., 1999) required the researcher to manipulate a manikin to mimic postures seen in field or to input segment angles, as well as time duration and hand forces. However, this methodology can be very time consuming as postures between participants may vary largely, requiring the input of various postures across participants for each action within a task. In addition, error may arise due to the subjective nature of manipulating the manikin to resemble the participant's actual posture. Other available methodologies include regression equations, such as developed by McGill et al. (1996), who presented a simple polynomial equation that can predict low back compression during complex three-dimensional tasks based on knowledge of the three-dimensional moments about the spine. The regression equation is easy to use for ergonomic purposes and considers muscle coupling and co-contraction. However, this study was completed with 3 male participants, making this generalized polynomial equation hard to apply to a largely female PSW population. van Dieën and Looze (1999) developed single muscle equivalents for the estimation of compression and anterior-posterior shear force in the sagittal plane for the low back which, like McGill et al. (1996), considers co-contraction, but also focuses on the effect of spinal curvature on compression and shear estimates. It is important to highlight that this methodology only works well for tasks that largely contain motion in the sagittal plane, which presents a challenge when quantifying PSW tasks that can contain motion in all three planes.

2.3.2. Peak and Cumulative Spine Moments

Cumulative low back moment has been identified to be strongly associated with development of LBP. Although some literature suggests that injury risk and LBP may be better predicted through measures of compression and shear, there is a strong correlation between measures of moment and bone-on-bone forces, therefore, lumbar moment can serve as a surrogate measure to represent MSD risk (van Dieën and Kingma, 2005). Norman et al. (1998) examined four biomechanical variables including peak spine loads, cumulative spine loads, trunk kinematics and hand loads and their association with LBP amongst workers in an automotive assembly facility. The aforementioned research group conducted a case-control epidemiological study and found that cumulative lumbar moment over a shift, along with hand force, peak shear force and peak trunk velocity were identified as the most predictive independent risk factors of LBP. Similar to Norman et al., Coenen et al. (2013) conducted a prospective cohort study examining the association between cumulative low back loads and LBP. The researchers used logistical regression analyses which revealed a non-linear relationship of cumulative low back moment and LBP, with incurred cumulative loads of more than 2.0 MNm subjecting individuals to a significantly higher risk of LBP. With a PSW population in mind, it is reasonable to assume that high levels of cumulative load are induced as a result of frequent patient lifts and patient handling (Daynard et al., 2001; Skotte et al., 2002). Lateral lumbar bending moment may also be an important metric to monitor cumulative damage as an increase in lateral bending moment contributes to an increase in disc compression forces (Marras and Granata, 1997). This may be important to consider in work that include many instances of asymmetrical work such as during many patient handling tasks (e.g., having the reposition client while standing on one side of the bed). Overall, a low back load dose measure proves to have a stronger relationship with LBP pain than exposure measures (e.g., repetition, external loads) as dose measures incorporate these aspects within a single measure.

Within research that focused on PSWs or healthcare support workers, there is overall less focus on cumulative lumbar moment in comparison to studies that have quantified cumulative compression and/or shear. Nelson et al. (2003) quantified forces on the lumbar spine during nine patient handling tasks that were identified to place high demand on nurses. Sixty-three nurses performed these tasks via standard procedures and per the researchers' redesigned tasks to determine if these redesigns lower exposure. The study took placed within a laboratory setting that was configured to represent a typical patient room within a hospital and the participant's manipulated a mannequin when performing the tasks. Using a 3D electromagnetic tracking system, electromyographical recordings and measurements of external force, lumbar spine forces and moments were calculated using a biomechanical model. However, no data values were provided regarding lumbar loads for the tasks completed according to standard procedures within this paper. Jäger et al. (2002) quantified lumbar moment in all three planes as well as compression and shear for several patient handling tasks. This study was conducted with a laboratory environment, where caregiver participants performed bed-related tasks with a hospital bed that had force sensors installed to measure forces that resulted from both the participant's actions as well as the patient actor's mass. As well, force plates were also used to capture ground reaction forces for the participant. This provided sufficient data to run through a 3D dynamic simulation tool developed previously by Jäger et al., producing sagittal bending, lateral and torsional moment at L5/S1. Although cumulative moment was not explicitly calculated within this paper, the time periods for each task examined were provided. With this said, the limitation with this study falls with its small sample size, with only 2 caregivers as participants. Studies conducted by King et al. quantified cumulative low back along with compression and shear for PSWs during toileting (King et al., 2019) and bathing tasks (King et al., 2020) completed in an actual bathroom environment. Due to the collection location, video footage was taken, and low back loads were analyzed using 3Dmatch software (University of Waterloo, Waterloo, Ontario, Canada). However, as these studies took place within a bathroom environment, kinetic measurements (e.g., hand force) were not taken, therefore, the calculated cumulative loads were underestimated. To conclude, although some subsets of PSW work tasks have been characterized, there has not been a comprehensive study to characterize a set of biomechanical exposures for a large range of PSW tasks, as completed by a robust sample of PSWs.

2.3.3. Linking Subjective and Objective Measures of Exposure

Subjective measures of exposures are used extensively in many occupations and industries, including within healthcare jobs. Tools such as the Borg Rating of Perceived Exertion (RPE) scale (Borg, 1990) have been used to evaluate the level of effort workers are expending to complete dynamic work tasks, where the individuals can score themselves to provide an exposure metric. These tools are relatively easy to apply within workplace, however, may provide less validity when estimating injury risk relative to objective exposure metrics such as low back forces or moments.

The Borg RPE scale is a psychophysical tool that is used to estimate and assess an individual's perception of effort/exertion when exercising or completing work (Borg, 1990). Perceived exertion is shaped by many factors, with Eston (2012) stating that RPE is largely influenced by an individual's afferent feedback from thermal (e.g., perspiration), cardiorespiratory (e.g., heart rate, breathing rate), and metabolic (e.g., lactic acid build-up in muscles) stimuli. Additionally, feed-forward mechanisms then allow for the individual to evaluate their level of exertion at instances of time. Scores can be representative of physiological, psychological as well as situational factors (Eston, 2012). Subject-specific characteristics such as gender, age and physical activity status, psychological factors such as understanding of the task, ability to focus, and cognition as well as activity characteristics such as activity type, duration and other temporal characteristics all influence perceived exertion (Eston, 2012).

Commonly, the Borg 6-20 or 15-point RPE scale is used for adults (Borg, 1971), but the Borg Category-Ratio-10 scale (CR-10) is also used frequently (Borg, 1982). RPE is used within sports, exercise and rehabilitation as a high correlation was found between RPE and physiological factors such as heart rate (Eston, 2012; Williams, 2007). Specifically, the Borg 6-20 RPE scale was developed on the basis that a strong relationship is present between perceived exertion and cardiorespiratory responses, where heart rate at an instance of time can be estimated by multiplying the RPE by ten (Borg, 1971; Borg 1990). Ratings from 6 to 20 have equal distances between the scores, with some scores having verbal anchors to assist individuals in accurately rating their perceived exertion (Borg, 1971).

Within past literature, the relationship between RPE and heart rate has been well explored, with the subjective scale often being used to monitor cardiovascular output and exercise intensity (Chow, 1984). RPE has also been used to estimate the effects of fatigue (Aryal et al., 2017; Zhao et al., 2022) and although less explored, the ability of RPE to be a possible surrogate for biomechanical exposure metrics such as joint moments or forces (Jane et al., 2007; Skotte et al., 2002; Thamsuwan et al., 2019; Winkelmolen et al., 2007).

Recently within the literature, researchers have been examining the relationship between subjective and objective exposure metrics, recognizing the benefits of estimating direct metrics associated with injury risk through data collected through easy-to-implement subjective tools if a relationship is present between the two metrics. Although not specifically pertaining to the PSW or health worker population, a feasibility study conducted by Thamsuwan et al. (2019) looked at the relationship between subjective and objective field-based exposure measures during harvesting tasks. The 6-20 as well as the CR-10 Borg scale were used to provide subjective exposure metrics in addition to the measurement of arms elevation and torso inclination with tri-axial accelerometers. Results from this study found that scores from both Borg scales appeared to be similar and mirrored general trends present in the posture measures, indicating that there is a potential benefit of using low-cost and easily implemented subjective measures as a surrogate of objective measures.

Other studies specific to healthcare work populations include Winkelmolen et al. (2007), who estimated lumbar compression forces and collected postural data during two-person manual lifting done by nurses. RPE scores ranged from approximately 12 to 15 for the different lifts. The researchers found that trunk flexion and lumbar compressive forces correlated positively with RPE scores, and rotation of the back correlated negatively with RPE scores. Jane et al. (2007) conducted a field study investigating spinal loading within a nursing population using both subjective and objective exposure metric. Using the 6-20 Borg RPE scale, the researchers collected post-task exertion scores for 200 different nursing activities and a correlation matrix was run to examine the relationship between RPE scores and estimated spine compression. Overall, a moderate positive correlation (0.543, $p<0.001$) was found between RPE and spine compression force. No RPE score values were reported however for the tasks examined. In contrast, Skotte et al., (2002) collected RPE scores using a 10-point Borg scale and calculated net lumbar moment, compression, and shear forces, finding that there was no correlation between the compression forces and RPE scores. It was noted by Skotte that the overall RPE scores were lower (1-2 on the RPE scale), however, within a lifting task, the RPE values could range from 0 to 8.

2.4. Literature Review – Conclusion

Based on the literature review conducted, it can be concluded that the increase in PSW injuries is an important issue that must be addressed as the demand for PSW services increases as well. Within current literature, there has been characterization of biomechanical exposures for work isolated tasks such as patient handling, however, these studies focus largely on other worker populations, such as nurses, and study work environments such as hospitals and LTC facilities. There is a gap in our knowledge regarding the biomechanical exposures on PSWs when performing their work tasks as relevant in a community-based care.

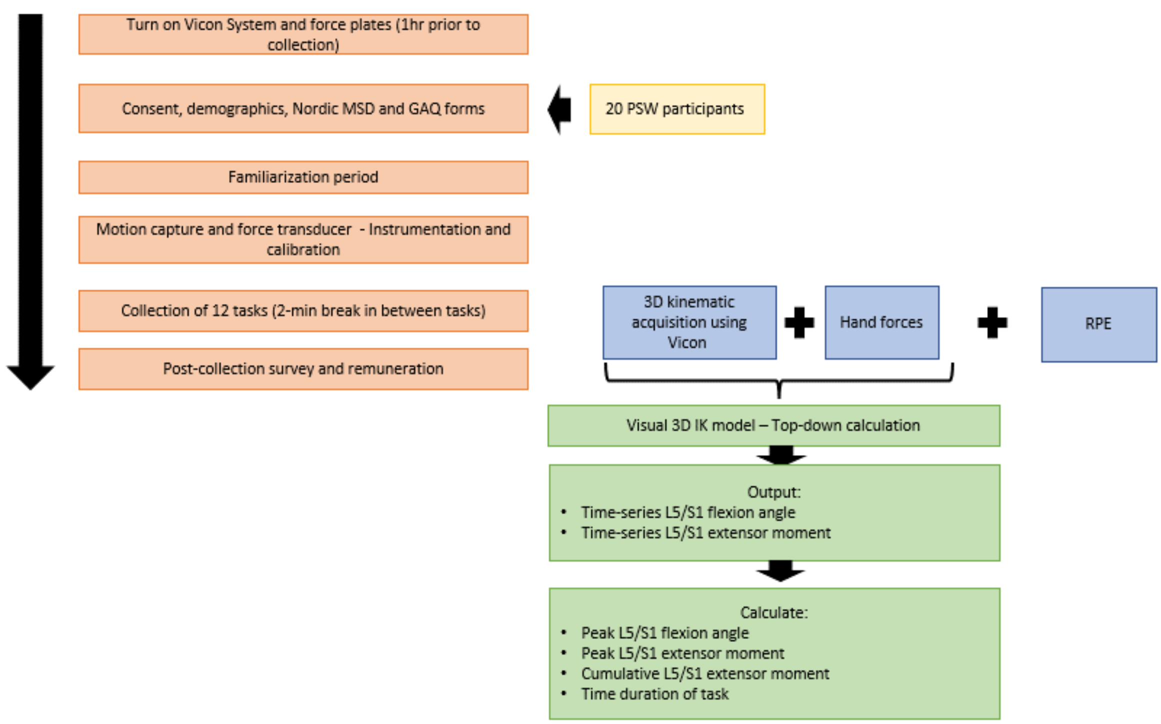
If we are able to characterize and quantify the biomechanical exposures experienced during PSW work, this will provide foundational knowledge that can support the development of injury prevention strategies and interventions. Specifically, workload management and continuous tracking of exposure metrics (or reasonable surrogates) may present as a more effective strategy in monitoring injury risk for PSWs when on the job. However, measuring exposures in a field-based setting is difficult, but emerging evidence suggests that low back biomechanical exposure metrics may have a strong enough association with perceived effort, warranting the possibility of being able to estimate low back loads with simple subjective tools. This warrants further examination of this relationship, especially within the PSW population who largely works within unconventional work settings as this present the potential for an easy-to-implement workload monitoring tool. As such, thesis aims to quantify the exposures associated with PSW work tasks within a laboratory-setting and to explore the relationship between perceived effort and biomechanical exposure metrics, which will provide the initial steps towards the development of a workload management system.

3.0. Methodology

3.1 Methodology Overview

A cross-sectional observational study was conducted to characterize biomechanical exposures experienced by PSWs. The specific tasks that PSWs were asked to perform were based on prior work (Ho et al., 2023), that identified the most physically demanding and frequently completed PSW tasks as performed primarily in community-based care settings. PSWs were invited into the laboratory, where the space was organized to reflect a home environment, consistent with community-based care. Kinematic and kinetic data were collected using 3D motion capture and hand force matching via a force transducer, which subsequently was used to calculate low back angle, peak moment, and cumulative moment. Subjective effort was also collected using the 6-20 Borg RPE scale. Figure 2 summarizes the experimental protocol and high-level data processing steps.

Figure 2. *Flowchart describing the experimental protocol, data acquisition and data processing.*



3.2 Participants

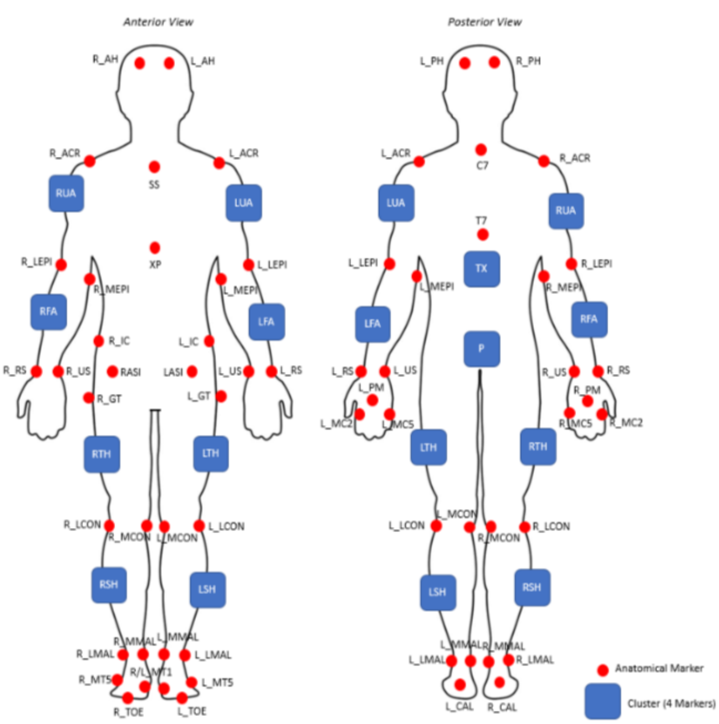
Twenty active PSWs were recruited from CBI Health and CarePartners (a national and an Ontario-based home healthcare provider, respectively). The inclusion criteria were active PSWs working full PSW duties and within the ages of 18-65. Potential PSW participants were excluded if they had sustained an injury that limited their ability to perform ADLs within the past 6 months, or if they were not currently actively working as a PSW, or if they were currently assigned to modified duties.

3.3 Instrumentation and Tools

3.3.1. Vicon® Motion Capture System

3D positional data of reflective markers placed on the participant were collected at 50 Hz using the Vicon Motion Capture system (Vicon, Centennial, CO, USA). The laboratory includes 12 cameras, and the collection volume was calibrated according to Vicon specifications (Vicon, 2016) where the origin was set as shown in Figure 3 (+Z upwards, +Y forwards, +X left of origin). A marker set consisting of 46 passive reflective markers (14mm diameter) were placed on anatomical and bony landmarks of the participant to define the local coordinate systems for each body segment (Wu et al., 2002, Wu et al., 2005). In addition, 10 rigid body marker clusters were attached to the upper arms, lower arms, trunk, pelvis, thighs, and shank. During collection trials, all required markers (non-calibration markers) and marker clusters remained on the participants to track the movement of each segment during dynamic motion. Therefore, a total of 86 markers were present during the calibration and 76 markers were present during the task trials (bilateral acromion, T7, C7, suprasternal notch, xiphoid process and bilateral greater trochanter were removed).

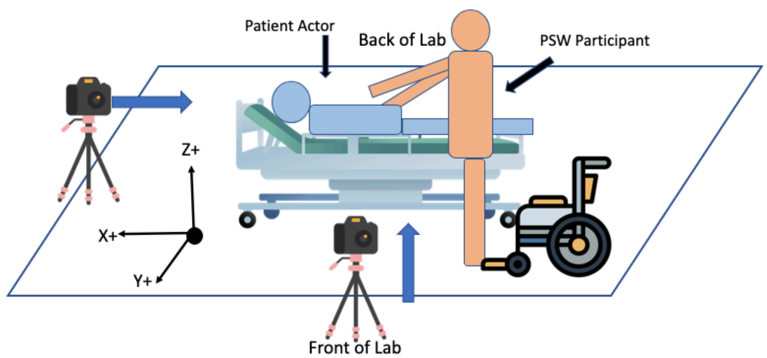
Figure 3. *Vicon marker placement.*



3.3.2. Video Cameras

Two Vicon Vue cameras were used to capture 2D video of the trials. These cameras were synchronized to the Vicon's motion capture system and were sampled at 25 Hz. The final placement of the camera in the lab space are showcased in Figure 4.

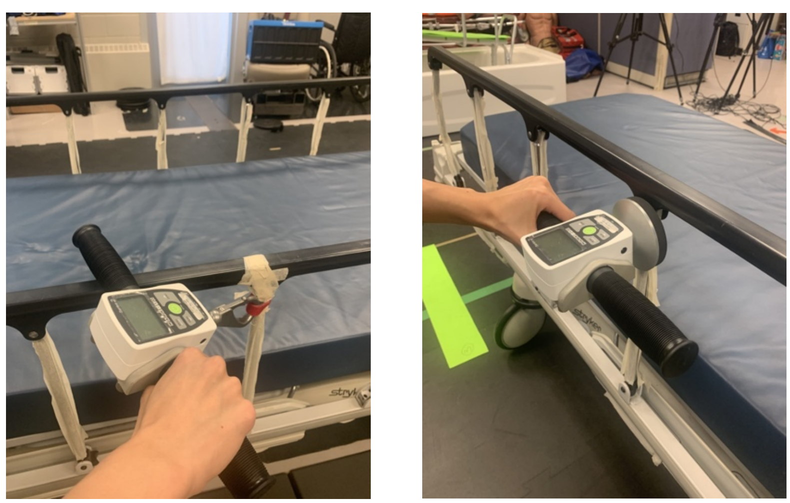
Figure 4. *Schematic diagram of laboratory setup for bed to wheelchair transfer.*



3.3.3. AMTEK® Chatillon Force Gauge

The Chatillon M2-200 force gauge (Amtek, n.d.) was used to measure hand forces (N) via force matching. The hook attachment was used during the force matching of pull movements while the flat disc attachment was used during the force matching of push movements (Figure 5).

Figure 5. *AMTEK Chatillon force gauge with the hook (left) and flat disc (right) attachment.*



3.3.4. 6-20 Borg RPE Scale

The 6-20 Borg RPE scale (Borg, 1971) was used to measure the participant's perceived exertion before and after each task trial (Figure 6).

Figure 6. *6-20 Borg Rating of Perceived Exertion scale (Borg, 1971).*

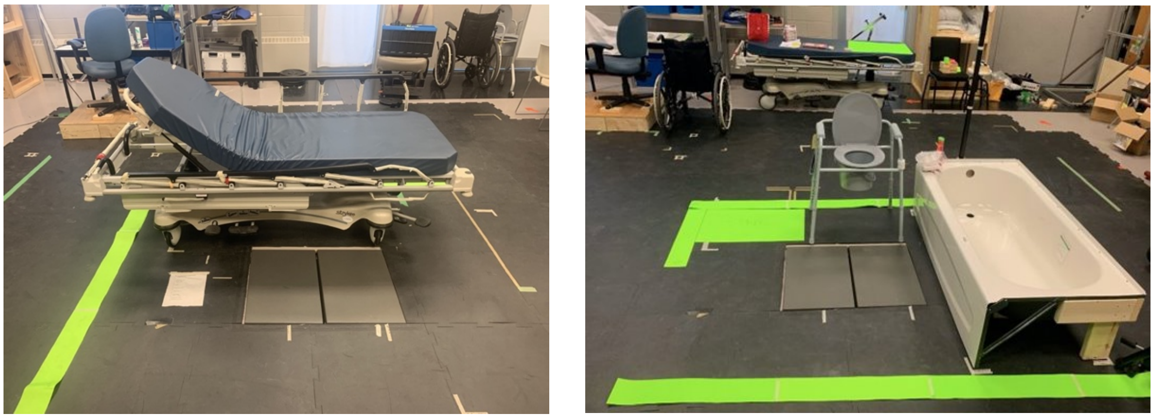
Rating	Descriptor
6	No exertion at all
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

3.4 Laboratory Setup

The laboratory space was organized in a manner to support participants in completing tasks as realistically as feasible and were informed by the training manager from one of the contributing workplace parties (Figure 7). The 12 tasks took place in two different collection space layouts: the bedroom and bathroom layouts. The appropriate equipment/fixtures were placed in the collection space along with bright coloured boarders in a specific orientation and dimensions to simulate rooms that can be found in a patient home. Participants were instructed that when completing the task trials, that they can interact with the equipment/fixtures and that they cannot step on or outside the borders.

The bedroom layout consisted of a corner space, where the top and one side along the long side of the bed was inaccessible. The bed's location in the space could not be moved. The bathroom layout consists of a 4.5 by 3-foot space, with an entrance, commode, bathtub, and sink (used borders to block off the space this fixture takes). Both the commode and bathtub location in the space could not be moved. These room layouts were used consistently across all participant collections.

Figure 7. *Laboratory set-up to reflect a bedroom (left) and a bathroom (right) that is representative of layouts found in a patient residence.*



3.5 Experimental Protocol

3.5.1. Instrumentation Calibration

Prior to collection, all instrumentation was calibrated. The Vicon system was turned on an hour prior to collection to prevent drift (Vicon, 2016). Camera calibration was performed using the Vicon Active Wand to describe the capture volume and the volume origin was set. Then, both static and dynamic calibrations were conducted, referencing the Vicon specifications (Vicon, 2016). A one second static calibration trial was collected at the start of each participants' collection session. Then, a dynamic calibration trial was conducted (range of motion trial).

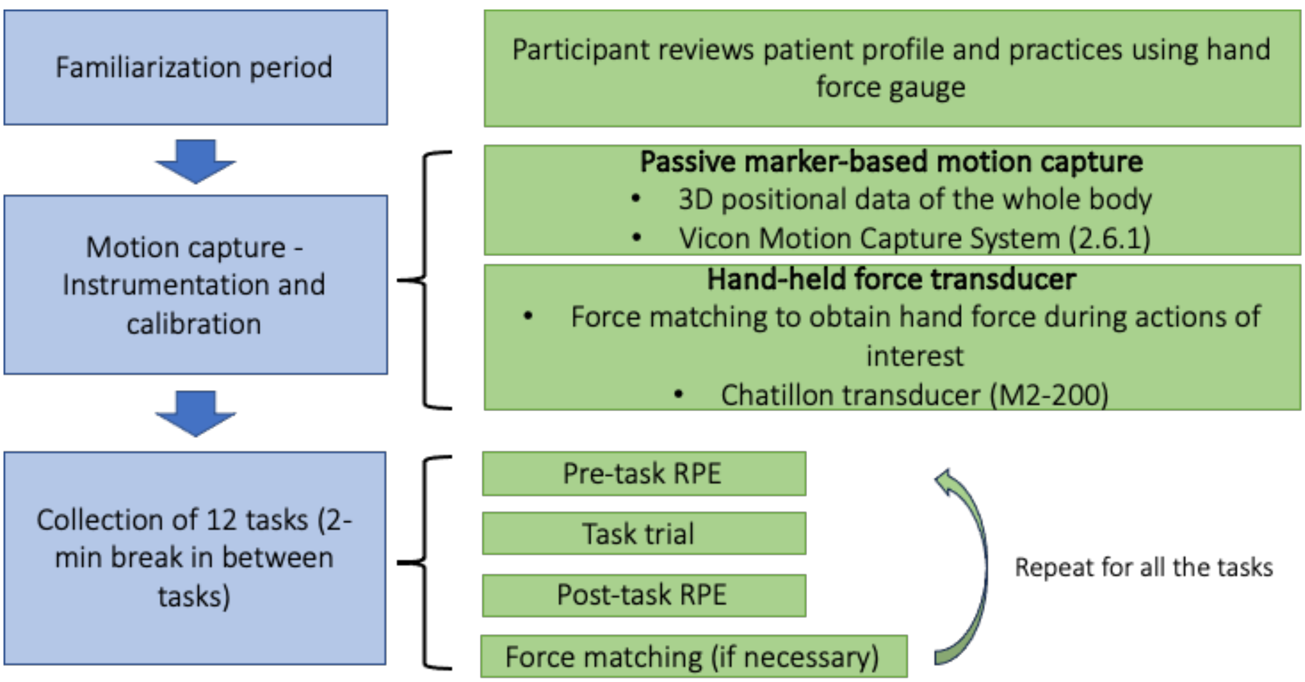
3.5.2. Participant Eligibility and Familiarization Period

Once participants arrived, they viewed a short presentation describing the purpose of the study and the collection procedure. After any of the participants' questions/concerns were addressed, they received an information letter describing the protocol and consent/withdrawal processes. After consent was given, participants completed a Get Active Questionnaire (GAQ) (CSEP, 2017) and the Nordic Musculoskeletal Questionnaire (NMQ) (Kuorinka et al., 1987) to confirm the absence of any contraindications to their participation (Appendix A and B). As well, participants completed a demographics form to provide their demographic characteristic (Appendix C).

The subsequent step in the collection process was a familiarization period (Figure 8). Participants were then provided with the patient profile (Appendix D), which contained information regarding the patient actor they would be interacting with for the collection. The patient profile contained information regarding their demographics, condition, and functional ability (this is further described in Section 3.5.5.). Once the participant reviewed the profile and any of their questions were answered, participants were instrumented. Prior to the completion of any task trials, the participant was provided with general instructions (Appendix D) regarding how to complete the tasks, focusing on specifying the patient actors initial and final positions (e.g., for a wheelchair to bed transfers, the patient's initial position is sitting on the wheelchair and by the end of the transfer, the patient should be laying down supine in the bed). Overall, the participant was able to complete the task as they saw fit, based on their experience and their interpretation of the patient profile.

Participants were introduced to the procedure of hand force matching that would take place during the collection and were given an opportunity to practice using it. Participants were informed that for any tasks that required a subsequent force matching tasks, they would be provided with a reminder to remember the amount of force used to complete the 'action of interest' within the task. The action of interest was defined as an action that was identified to likely subject the participant to the highest low back extensor moment (Daynard et al., 2001) For example, for the wheelchair to bed transfer, the action of interest was identified as when the participant assists the patient to stand up from the wheelchair. The identification of the action of interest is further detailed in Section 3.5.6.

Figure 8. *Summary of preparation, instrumentation, and task trial collection.*



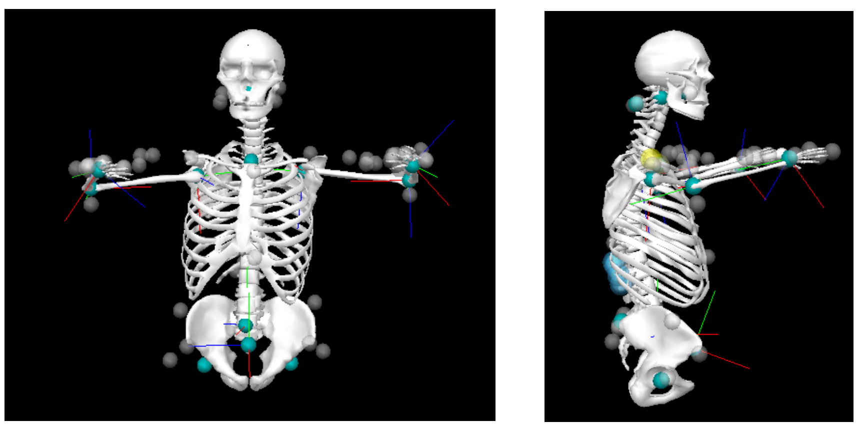
3.5.3. Participant Instrumentation

After the familiarization period, the participant was instrumented with motion capture markers. With the participant instrumented with the full marker set, a static and dynamic calibration trial was collected. For the rest of the task trials, the calibration markers were removed.

3.5.4. Collection Procedure

For each task trial, the correct layout was configured, and equipment/fixtures were brought into the collection space. The participant started each trial by standing in 'motorbike' position at the back of the lab to ensure that all markers were captured and were not obstructed by the equipment (Figure 9). Once the researcher started the collection on Vicon, they would inform the participant to walk over to the force plate in the center of the collection space. Once standing on the force plate, the participant was instructed to stomp their left foot down before starting to complete the task (the foot stop was necessary to synchronize other data that was collected concurrently with this study). The participant then completed the task and would return to the back of the lab to their initial starting position to complete the recording. Participants would then adopt the motorbike position again and the task trial would end. Participant's RPE scores were collected before and after the completion of each task using the 6-20 Borg scale.

Figure 9. *Motorbike position adopted motorbike position at the beginning and end of all task trials.*



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3.5.5. Task Trials

All participants completed a total of 12 work tasks, with each task separated by a 2-minute break in between to prevent fatigue. The tasks are displayed in Figure 10 and abbreviations for the tasks are described in Table 1. Henceforth, the tasks will be referred to using the abbreviations within tables and when referencing descriptive statistics. The work tasks were completed at a self-selected pace and the task order was block-randomized (Appendix E) for each participant, similar to procedures conducted by Daynard et al. (2001), to minimize the effects of fatigue.

Figure 10. *The 12 PSW work tasks completed by participants, consisting of commonly and physically demanding PSW tasks.*

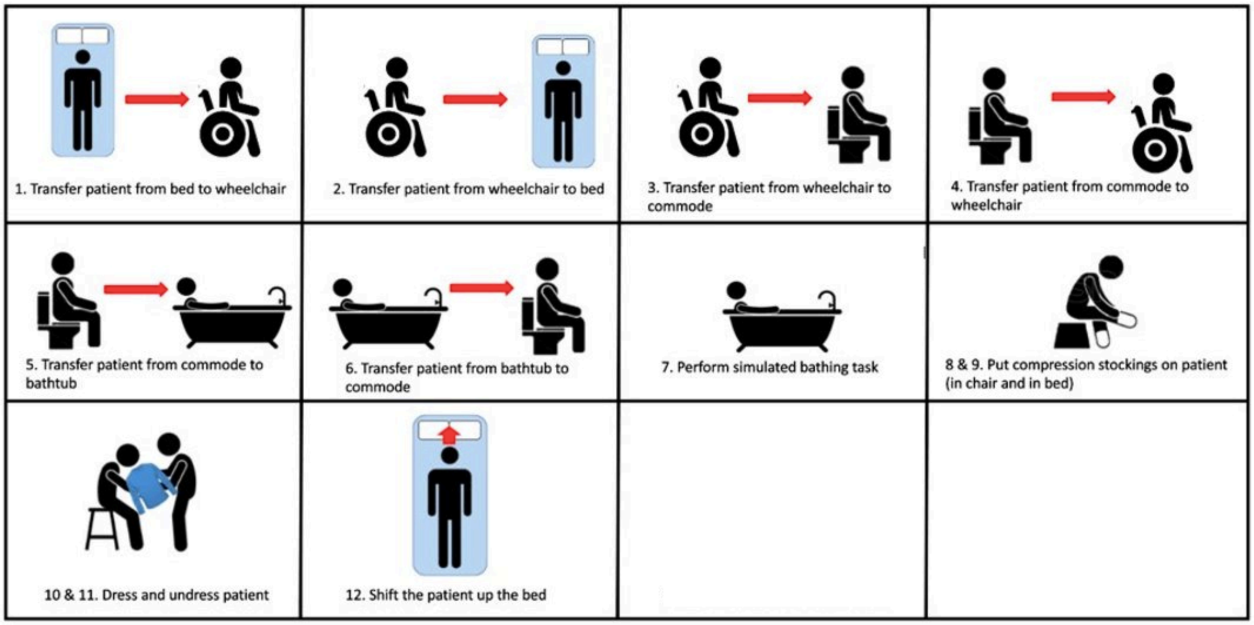


Table 1. *Abbreviations for all tasks.*

Task	Abbreviation
Bathing patient	bath
Bed to wheelchair transfer	bed-wc
Bathtub to commode transfer	bt-com
Commode to bathtub transfer	com-bt
Commode to wheelchair transfer	com-wc
Dressing the patient	dress
Repositioning the patient up the bed	repost-bed
Applying compression stockings on to the patient, patient lying in bed	socks-bed
Applying compression stockings on to the patient, patient sitting on the commode	socks-com
Undressing the patient	undress
Wheelchair to bed transfer	wc-bed
Wheelchair to commode transfer	wc-com

Participants completed all tasks with a patient actor, where the same patient actor was used for all participants for consistency. The patient actor was trained to mimic specific functional traits that were selected based on prior work (Ho et al., 2023), which found that high patient weight and low patient mobility increased the physical demand of PSW work tasks the most. The patient actor mimicked having limited lower body mobility and strength, who was unable to bear much weight in addition to wearing a weighted vest and ankle weights to increase their body weight to 86kg. This body weight was selected as 86kg represents the 75th percentile measured weight of the Canadian population (Statistics Canada, 2015).

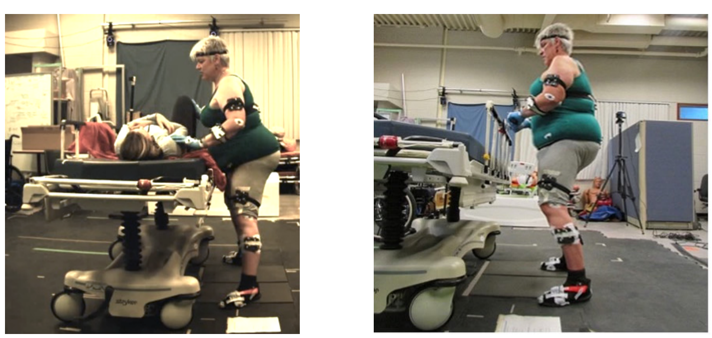
The 12 work tasks are described in Appendix E. Once the task trial collection begins, the participants could adjust certain aspects of the equipment/fixtures such as the height of the bed and the position of the wheelchair before completing the task. Some aspects of the equipment/fixtures were non-adjustable such as the location of the bed, bathtub and commode in the collection space and the heights of the shower chair, commode, and wheelchair (which were previously height-adjusted for the patient actor by the researchers prior to all collections). The height of the bed was pre-adjusted by the researchers to be suitable for the patient (e.g., patient's feet are on the ground if sitting on the bed) as a consistent starting height across all participants.

3.5.6. Hand Force Matching

For the transfers and the bed repositioning tasks, hand force matching was completed to obtain the force required to manipulate the patient (Table 2). Actions of interest were identified for these tasks and included instances where the participants were required to exert higher forces (e.g., lifting the patient actor, rolling the patient) and/or in a non-neutral posture (e.g., highly flexed spine, twisted spine).

In each hand force matching case, the participant adopted a similar posture that they were in during the actual task trial and the force gauge was attached to the equipment that they were interacting with at a similar height at which the participant was exerting force onto the patient actor (Figure 11). The participant was then instructed to slowly ramp up applying force to the force gauge (push or pull, depending on the movement) until they reached the approximate force that they used during the actual task trial. The force gauge records the peak force, and this value was retained for analysis. Hand forces were collected once for every action of interest.

Figure 11. *Force matching when participant is completing the task of repositioning the patient up the bed.*



Note. The participant rolls the patient away from themselves (left) and force matches (right).

Table 2. *Hand force matching completed for transfer and patient repositioning tasks.*

Tasks	Initial Starting Location	Movement	Hand Force Matching Procedure
Transfers			
Bed to wheelchair	Bed - Assisting patient actor to stand from bed	Pull upwards	The hook attachment was used, and the force gauge was attached to the railing of the bed.
Bathtub to commode	Bathtub - Assisting patient actor to stand from shower chair	Pull upwards	The hook attachment was used, and the force gauge was attached to the shower chair seat.
Commode to bathtub Commode to wheelchair	Commode - Assisting patient actor to stand from commode	Pull upwards	The hook attachment was used, and the force gauge was attached to the commode arm rest.
Wheelchair to bed Wheelchair to commode	Wheelchair - Assisting patient actor to stand from wheelchair	Pull upwards	The hook attachment was used, and the force gauge was attached to the wheelchair arm rest.
Patient Repositioning			
Shifting patient up the bed	Bed – Patient is laying down supine near bottom of the bed	Roll away from participant (push)	The flat disc attachment was used, and the force gauge was pushed into the railing of the bed.
		Roll towards participant (pull)	The hook attachment was used, and the force gauge was attached to the railing of the bed.
		Pull patient up the bed	The hook attachment was used, and the force gauge was attached to the railing of the bed.

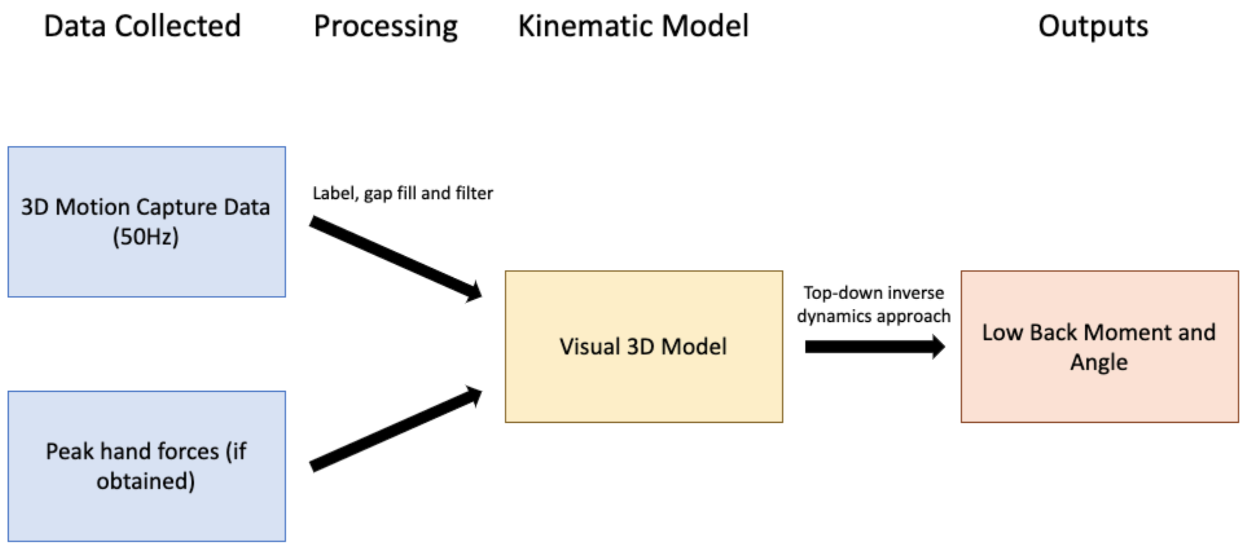
3.5.7. Collection Conclusion

Once participants completed all the task trials, instrumentation was removed from them, and participants received remuneration ($100) for completing the study. In addition, the participants completed a post-collection survey (Appendix F) which asked the participants to rate how realistic the tasks completed during the study were compared to how the tasks are completed in their real work using a scale of 1-10.

3.6. Data Processing and Conditioning

With the collected data, subsequent data processing and conditioning was completed on the kinematic data to be build models. Kinetic measures were then applied, and low back exposure metrics were calculated through a top-down, inverse dynamics approach (Figure 12).

Figure 12. *General flow of data collection, processing, and analysis to obtain low back moment and angle outputs.*



3.6.1. Labelling and Gap-filling 3D Motion Capture Data

Motion capture data were processed in Vicon Nexus 2.6.1 (Vicon, Centennial, CO, USA). Raw marker data for each participant's trial (calibration and task trials) were reconstructed and labelled. Each reconstructed trial was visually analyzed frame-by-frame to ensure that trajectories were properly labeled and free of any gaps. If gaps were present, 'rigid body fill' was used first, which fills in marker gaps based on the unchanging distance between the missing marker and three other markers on the same segment. If 'rigid body fill' was not possible, 'pattern fill' was used which fills in marker gaps based on the assumed unchanging distance between the missing marker and one other marker on the same segment. The last option used to gap fill was 'spline fill', which was only used for gaps smaller than 10 frames (Howarth and Callaghan, 2010). Once the static calibration trial was properly labelled and gap-filled, a calibration pipeline was used to streamline the labelling of the dynamic calibration trial. Similarly, the dynamic calibration trial was assessed frame-by-frame to ensure correct labelling and any gaps were filled, followed by the execution of a functional calibration pipeline to automate the labelling of the task trials.

3.6.2. Modelling within Visual 3D

The labelled motion capture data was then exported to Visual 3D (C-motion Inc., Germantown, MD, USA), along with the participant's demographic information (participant weight). A dual-pass, low-pass 4th order Butterworth filter with an effective frequency cut-off of 6 Hz was applied (Winter, 1990) to the motion capture data. Using the static calibration trial, a skeleton model and landmarks were created for each participant, with the corresponding landmark orientations set. Then, the segments were created by defining the proximal joint and distal joint (and the corresponding radii). For segment masses, the Dempster's regression equations (Dempster, 1955) were used (as set as default within Visual3D). The moment of inertia of a segment as well as the centre of mass locations were set as per Hanavan's mathematical model (Hanavan, 1964). In term of segment geometry, the trunk and pelvis were cylindrical, while the limbs were all conical. The model created used the segment definitions and joint locations described in Table 3.

Inverse kinematic constraints were applied to the rigid link segment models to restrict degrees of freedom (DOF) between segments based on how joints move (through default settings: algorithm for computing pose is Visual3D 6DOF, optimization algorithm is Levenberg Marquardt). For all task trials, a top-down modelling approach was used.

Due to some challenges regarding marker occlusion, some task trials had missing hand markers. For tasks trials where the hands were not present, a separate Visual3D model was used. This model did not contain hands, rather, the mass of the forearm segment was changed to reflect the mass of both the forearm and hand and the center of mass was changed as well to reflect the location (along the long axis of the forearm) if considering the forearm and hand as one segment (Dempster, 1955).

The skeleton model created using the static calibration trial was used to process all task trials and the visual representation of the model was used to review and ensure that all prior Vicon marker labelling was correct. If any errors (e.g., mislabelled markers) was detected, corrections were made in Vicon before proceeding forward in any processing in Visual 3D. Once all task trials were assessed to be correctly labelled, several steps had to be taken prior to the calculation of any outputs of interest.

Table 3. *Segment definitions – Identifying the distal/proximal segment points and calculation of joint center locations.*

Segment	Definition
Torso	Proximal joint center: mid-point between the left and right acromion markers Distal joint center: mid-point between the left and right iliac crest markers Depth of torso: distance between the suprasternal notch and C7 markers
Upper arm	Proximal joint center/shoulder joint center: - Starting point: acromion - End point: mid-point between left and right acromion markers - Lateral object: mid-point between the left and right iliac crest markers - Offset in axial direction by 0.05% - Radius: midpoint between lateral and medial epicondyles Distal joint center/elbow joint center: midpoint between lateral and medial epicondyles - Radius: midpoint between L_EPI and M_EPI
Forearm	Proximal joint center: elbow joint center Distal joint center/wrist joint center: midpoint between ulnar styloid marker and radial styloid marker - Radius: midpoint between L_EPI and M_EPI
Hands	Proximal joint center/wrist joint center - Distal lateral landmark: H1 - Distal medial landmark: H2 Tracking targets: H1, H2, H3
Pelvis	Segment type: Coda pelvis (*Coda Pelvis*, 2019) - Defined using anatomical location of the ASIS and PSIS (ASIS and PSIS used as reference points of defining pelvis coordinate system) Proximal/Origin point - Mid-point between ASIS markers Distal point - Mid-point between P1 and P4 marker on the pelvis cluster (approximately where sacrum is located) o The Coda pelvis uses the midpoint between the PSIS to identify where the sacrum is located Orientation - X-Y plane: through R_ASIS and L_ASIS and mid-point of the R_PSIS and L_PSIS (in this case, we defined mid-point between PSIS as SACR) - x-axis: origin to R_ASIS - y-axis: perpendicular to X-Y plane - z-axis: cross product of z-axis and x-axis

Note. 'L_EPI and R_EPI' – left and right epicondyles, 'H1, H2, H3' – hand markers, 'L_ASIS and R_ASIS' – left and right anterior superior iliac spine, 'L_PSIS and R_PSIS' – left and right posterior superior iliac spine, 'SACR' – sacrum.

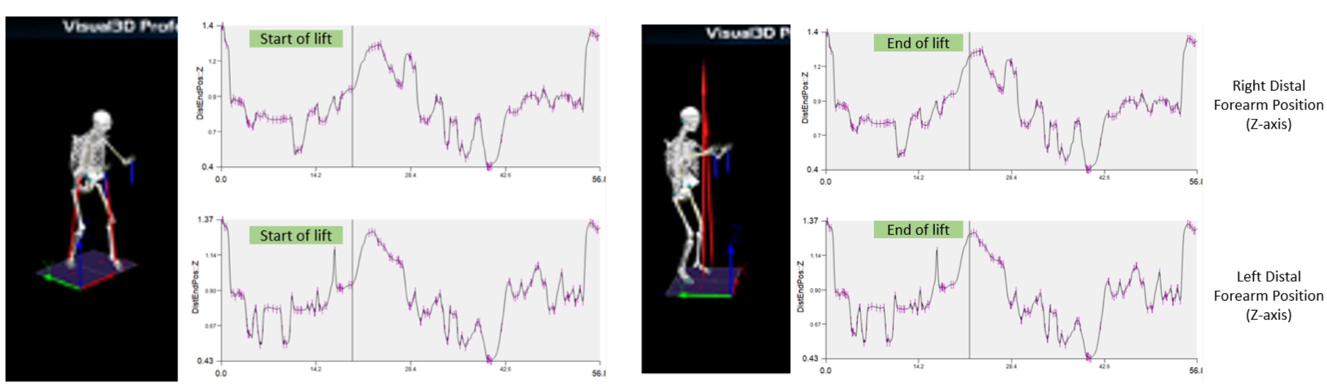
3.6.3. Identifying Events

The start and end of tasks were defined in a manner that is consistent as possible across all task trials as this is pertinent in the calculation of cumulative loading and considering task duration as an exposure metric (Fischer et al., 2007).

The start of every task was defined as the frame after the participant has walked over the force plates and performed a stomp. Therefore, the peak in force measured from the plates indicated the start of the task. The end of very task was defined as the frame when the participants start to walk back to their initial starting position after completing the task. Once these events were identified, the task trials were cropped within Visual3D to match.

In addition to defining the start and end of the tasks, the start and end of key actions of interest were necessary to inform when to input hand forces. For the six transfer tasks, the actions of interest were defined as the time when the participant assists the participant to stand from their initial starting location. The start and end of the lift was defined using context from the video footage and the distal end position of the participant's forearms in the vertical direction (Z-axis) (Figure 13). Firstly, the video footage obtained was reviewed to identify approximately where the start and end of lift occurred, excluding instances where the participant is adjusting their lifting posture prior to performing the actual lift. To precisely identify the start and end events, within Visual 3D, a pipeline was created to identify quick changes in the distal forearm position signal to create event markers. If the signal's rate of change exceeded 0.70, event markers were created. Using context from the video footage combined with the event markers that indicate instances of rapid changes in the distal forearm position, the start and end of lift was identified in a consistent manner across all task trials. Within the distal forearm position signal, the start of lift was be identified by the signal plateauing before a sharp increase as the participant's distal forearm goes up while the end of the lift can be identified by a plateau following the sharp increase that occurs.

Figure 13. *Identified the start (left) and end (right) of the lift during a bed to wheelchair transfer.*



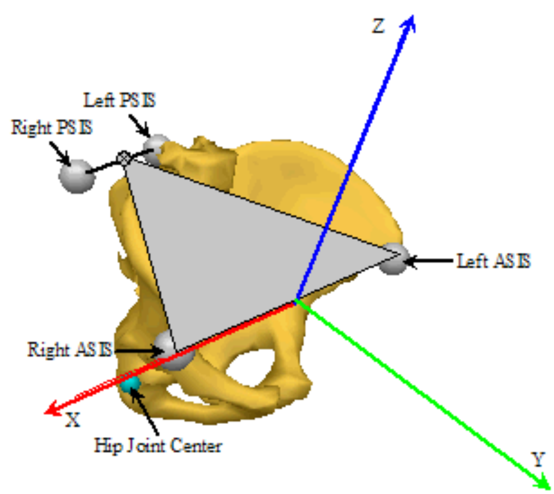
3.6.4. Applying Hand Forces

Hand forces were applied at the wrist joint centers across all tasks. The peak force value collected was split equally across both hands unless evaluated via video footage that only one hand was used during the action of interest. (e.g., right hand was placed on the participant during a lift while the left hand was hovering/completely off the participant).

3.6.5. Time-Series Low Back Angle and Moment – Calculation and Processing

Once all prior steps were completed, time-series low back angle and moment measures were calculated on Visual 3D (Table 4). Low back angle was defined as the angular displacement between the torso and pelvis segments, with the pelvis defined as the reference segment and the torso as the final segment. Through matrix rotations, in the sequence Z-Y-X, low back flexion angles were calculated. An extension bias was present throughout all trials due to the use of a CODA pelvis and how it is modelled, where the pelvis transverse plane is tilted anteriorly approximately 20 degrees (Figure 14). To remove the extension bias, 20 degrees was removed from each data point within sagittal low back angle time-series data for all participants; thus, upright standing was zero, flexion was negative, and extension was positive.

Figure 14. *The Coda pelvis: Markers used for defining the segment and its associated coordinate system.*



Note. Pelvis coordinate system shown is default to the CODA pelvis. Coordinate system utilized within the current study is modified (+Y-axis for distal to proximal, +X-axis for anterior to posterior, +Z-axis for lateral to medial)

Low back extensor moment measures were calculated. A top-down approach was used to calculate joint moments about the distal torso 'joint', which was defined as the sacrum (approximately L5/S1 level), relative to the torso segment. Therefore, the joint moments were resolved within the torso coordinate system. All data was exported as ASCII files to be analyzed further.

Table 4. *Summary of outputs calculated and exported within Visual3D for all trials.*

Output	Degree of Freedom	Direction
Low Back Angle (degrees)	Flexion	Negative around X-axis
	Extension	Positive around X-axis
Low Back Moment (Nm)	Extensor	Positive around X-axis

3.6.6. Calculating Outputs Measures

Peak low back flexion angle, peak low back extensor moment and cumulative low back extensor moment were calculated and analyzed using MATLAB (Version: 9.13.0 (R2022b). Peak low back flexion angles were calculated for each task trial in addition to peak and cumulative low back extensor moments. Cumulative extensor moments were calculated using point-by-point trapezoidal integration for each task trial, considering only extensor moments (positive values). Additionally, from the study collection, post-task RPE scores and task duration times were compiled.

3.7. Statistical Analysis

3.7.1. Descriptive Statistics

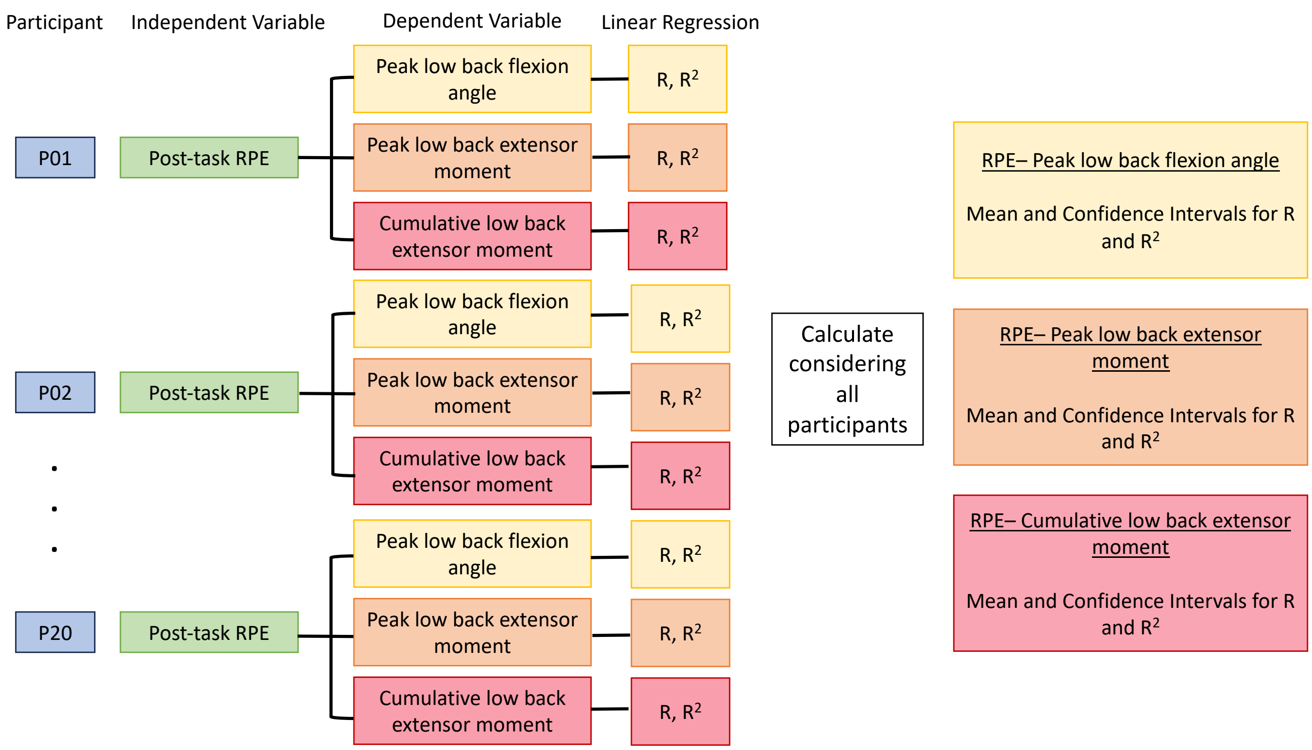
To address research question 1, descriptive statistics were used to examine and better understand the data. To visually examine the range and distribution of the data across participants, frequency histograms were generated across all tasks for the following output variables: 1) Peak sagittal flexion angle, 2) Peak extensor moment, and 3) Cumulative extensor moment. In addition, the means, standard deviation, and ranges were calculated for the aforementioned output variables as well as for task time duration and post-task RPE scores.

Amplitude probability distribution functions (APDFs) were also generated from the low back flexion angle and extensor moment following recommendations from Jonsson et al. (1982). Although APDFs are typically used to examine the distribution of the muscle contraction levels during a certain observation period, for the purposes of this thesis, this concept was utilized for the examination of the frequency at which participants were engaging in certain levels of low back flexion and were exposed to certain low back moments. From the generated APDFs, ranges in degrees of flexion were identified, corresponding to mild (0-20 degrees), moderate (20-45 degrees) and severe (>45 degrees) flexion, to facilitate comparison across tasks (Burdorf & Van Riel, 1996; King et al., 2019; King et al, 2020). As well, the 50th percentile and 90th percentile was used as a comparison point between tasks for low back extensor moment.

3.7.2. Inferential Statistics for Hypothesis Testing

To address the hypothesis for research question 2, linear regression analyses were completed at the level of the individual participant to evaluate the relationship between post-task RPE scores and the objective low back exposure metrics (peak low back flexion angle, peak low back extensor moment, cumulative low back extensor moment). Participant-specific analyses were completed to examine if the strength of the relationship between RPE and the low back exposure metrics is dependent on the individual, and if so, observations can be made regarding their characteristics to understand what aspects of those individuals may have resulted in a stronger relationship between the variables of interest. The mean and confidence intervals for R and R^2 values were calculated for each low back exposure metric, considering all participant's results.

Figure 15. *Flowchart of linear regression analyses.*



Several considerations were made prior to any statistical testing. Firstly, post-task RPE scores were selected to be the independent/predictor variable as the scores themselves are associated with a specific level of exertion (e.g., light, strong, etc.). As our study protocol contained breaks in between task trials to mitigate fatigue and pre-task RPE scores were all close to baseline, it was deemed that participants were at or close to baseline exertion before every task and therefore, post-task RPE scores are reflective of the perceived exertion to complete a task. Secondly, RPE scores are typically considered to be ordinal in nature, however as the categories on the scale are evenly spaced and were normally distributed, the scores can be treated as continuous (Long & Freese, 2006). Lastly, assumptions for linear regression were tested, with normality tested through interpretations of P-P plots, homoscedasticity through predicted value – residual scatterplots, and linearity through the two aforementioned tests (Appendix F).

Additionally, a correlation matrix was calculated to evaluate the association between the objective exposure metrics (peak low back flexion angle, peak extensor moment and cumulative extensor moment). Linear regression analyses were completed in Microsoft Excel (Version 16.76) and the correlation tests were completed using IBM SPSS Statistics (Version 29.0.0.0).

4.0. Results

4.1. Demographics

Twenty PSWs from two different healthcare providers (CBI Health, CarePartners) participated in this study, including 17 females and 3 males. Participant demographics are detailed in Table 5. From the demographics form, additional information was provided by participants regarding the approximate number of patient visits and work hours per day and per week (Table 6). As well, participants estimated the frequency at which they completed the tasks examined in this study (Table 7).

Table 6. *Patient demographics.*

Participants	n	20
Sex	F	n=17
	M	n=3
	Mean	SD (±)
Age (years)	43.1	13.3
Height (m)	1.65	0.1
Weight (kg)	74.3	22.9
Years of Experience	8.5	7.8

Table 5. *Number of patient and work hours per day and per week.*

			Range	
	Mean	SD (±)	Low	High
Number of patients per workday	6.5	4	1	18
Number of patients per work week	33.3	31.4	3	120
Work hours per day	7.6	2.7	3.5	12
Work hours per week	38.2	16.9	4	71.5

Table 7. *Frequency of tasks per day and per week.*

	Frequency per day		Frequency per week	
Task	Mean	SD (±)	Mean	SD (±)
dress and undress	7.4	3.7	34.0	21.2
bath	4.9	3.4	23.4	20.6
bed-wc	3.4	4.2	13.1	14.5
wc-bed	3.2	4.3	12.4	14.7
repost-bed	3.1	4.9	10.3	14.5
wc-com	2.4	2.4	9.3	11.3
com-wc	2.4	2.4	9.2	11.4
socks-bed and socks-com	1.7	1.5	6.7	8.2
com-bt	1.3	1.5	6.1	7.7
bt-com	1.3	1.8	5.1	7.7

4.2. Biomechanical Analysis

4.2.1. Task Time Duration

The task time duration varied between tasks, with patient bathing (218.5 ± 66.1s), compression stocking application (socks-chair 144.6 ± 46.4s) and dressing the patient (134.6 ± 33.3s) having the longest task times (Table 8). Shorter task time durations were found for transfer tasks, with transfers between the wheelchair and commode (wc-com 49.8 ± 18.2s; com-wc 46.6 ± 17.0s) and between the commode and bathtub (com-bt 52.6 ± 13.0s; bt-com 58.6 ± 19.5) having the shortest completion times. In addition to variability across tasks, variability was present between PSWs within a task. Longer duration tasks, such as bathing (range 142.5s - 331.4s) and compression stocking application (range 83.8s - 297.9s) had the widest range between PSWs.

Table 8. *The mean, standard deviation, and range for task time duration for each task.*

	Task Time Duration (s)			
			Range	
Task	Mean	SD (±)	Low	High
bath	218.5	66.1	142.5	331.4
socks-chair	144.6	46.4	83.8	297.9
dress	134.6	33.3	85.8	200.4
socks-bed	127.6	51.0	64.1	255.7
repost-bed	113.0	34.5	55.3	189.3
undress	80.7	17.0	57.2	114.1
bed-wc	79.4	25.3	52.2	147.9
wc-bed	77.6	29.8	43.2	151.5
bt-com	58.6	19.5	29.1	94.0
com-bt	52.6	13.0	35.3	86.8
wc-com	49.8	18.2	22.9	100.8
com-wc	46.6	17.0	20.9	90.0

4.2.2. Low Back Flexion

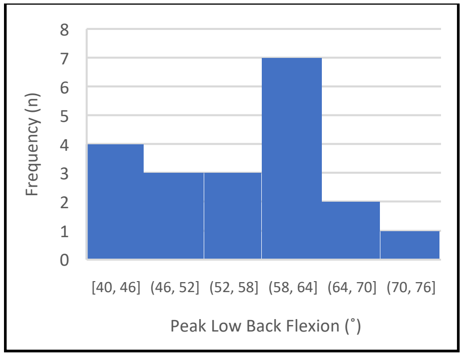
Sample means in peak low back flexion ranged from 35 to 57 degrees across all tasks, with the highest flexion occurring during the dressing and undressing tasks (dress 55.9 ± 10.6˚; undress 57.5 ± 10.5˚), bathing (55.1 ± 8.5˚) and when applying compression stockings (socks-bed 50.5 ± 10.8˚; socks-com 56.6 ± 11.0˚). Lower sample mean peak flexion values were captured during transfers between the wheelchair and commode (wc-com 37.5 ± 8.6˚; com-wc 35.4 ± 9.2˚). The standard deviation across tasks was similar, ranging from approximately 8-11 degrees. Between participant variability within tasks was also evident. Tasks such as bathing, dressing and undressing, and compression sock application demonstrated an approximate range difference of 40 degrees. Transfer tasks resulted in range difference of around 30 degrees across the participant sample. A detailed analysis of the data can be seen in Table 9 and frequency distribution in Figure 16.

Table 9. *The means, standard deviations (SD) and ranges for peak low back flexion (a), peak extensor moment (b) and cumulative extensor moment for each task (c).*

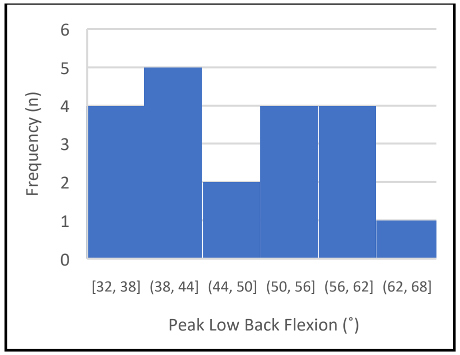
a) Peak flexion angle (degrees)					b) Peak extensor moment (Nm)					c) Cumulative extensor moment (Nm*s)				
			Range					Range					Range	
Task	Mean	SD (±)	Low	High	Task	Mean	SD (±)	Low	High	Task	Mean	SD (±)	Low	High
undress	57.5	10.5	36.9	79.2	wc-com	156.1	69.4	68.4	328.4	bath	8008.6	4716.3	2745.2	20817.0
socks-com	56.6	11.0	33.0	78.7	wc-bed	155.2	73.4	74.0	353.1	socks-com	6719.1	3488.8	2286.3	16278.2
dress	55.9	10.56	33.7	72.2	bed-wc	153.78	72.8	70.1	378.2	socks-bed	5863.3	3168.2	1766.3	13177.3
bath	55.1	8.6	39.8	70.3	com-wc	150.2	86.7	49.9	447.7	dress	4971.1	2559.8	1810.6	11825.2
com-bt	54.3	12.6	31.3	81.3	com-bt	150.1	80.3	69.4	421.1	repost-bed	4552.3	2283.3	1509.8	10790.0
bt-com	54.1	10.2	34.0	68.7	bt-com	148.1	66.8	65.0	343.6	wc-bed	3112.5	1578.5	1117.7	7435.6
wc-bed	51.0	9.4	32.6	68.4	repost-bed	115.3	50.2	66.7	258.7	bed-wc	2824.2	1534.1	1015.4	6854.8
socks-bed	50.5	10.8	32.2	74.8	undress	106.0	39.4	59.1	211.7	undress	2623.0	1268.1	1122.0	5759.0
bed-wc	48.1	9.4	32.1	63.2	dress	105.5	44.2	71.6	233.4	bt-com	2338.5	1395.4	885.3	5632.1
repost-bed	45.4	10.6	30.0	72.5	bath	105.2	36.7	63.2	196.6	com-bt	1943.9	898.8	846.1	3802.9
wc-com	37.5	8.6	21.8	51.5	socks-com	98.6	42.9	59.5	213.8	wc-com	1502.3	1348.2	408.0	6493.9
com-wc	35.4	9.2	20.2	56.4	socks-bed	92.7	31.3	59.1	173.4	com-wc	1329.3	916.7	344.1	3670.6

Note. Tasks are ordered from highest to lowest with respect to each outcome measure. Abbreviations used in this table: ‘bed-wc’ – bed to wheelchair transfer, ‘bt-com’ – bathtub to commode transfer, ‘com-bt’ – commode to bathtub transfer, ‘com-wc’ – commode to wheelchair transfer’, ‘dress’ – dressing patient, ‘repost-bed’ – repositioning patient up the bed, ‘socks-bed’ – compression stocking application with patient on a bed, ‘socks-com’ – compression stocking application with patient on commode, ‘undress’ – undressing patient, ‘wc-bed’ – wheelchair to bed transfer, ‘wc-com’ – wheelchair to commode transfer.

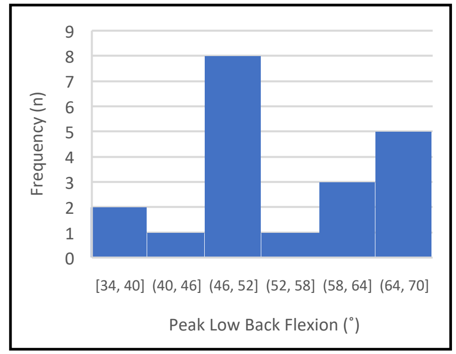
Figure 16a-l. *Frequency histograms for mean peak low back flexion (degrees) across all tasks.*



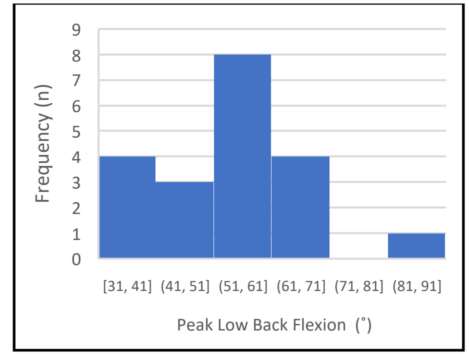
a) Bath



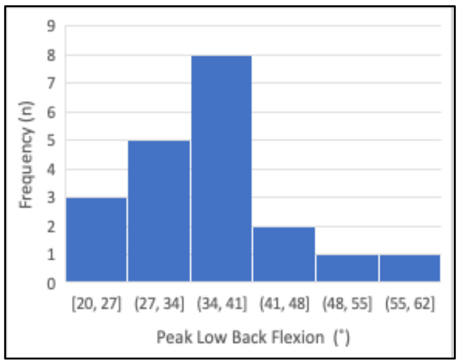
b) Bed to wheelchair transfer



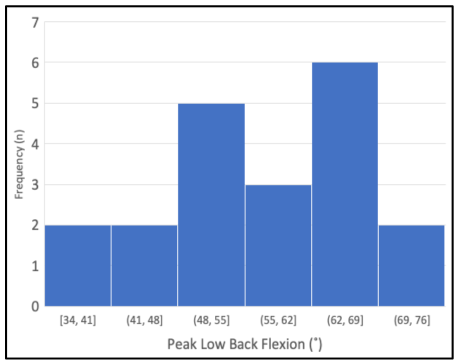
c) Bathtub to commode transfer



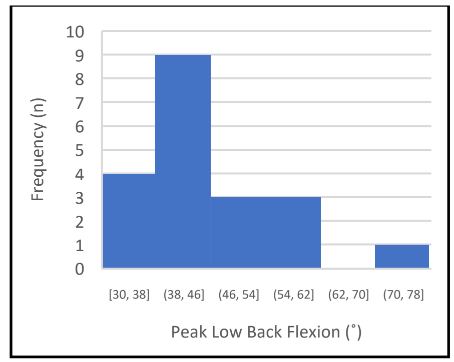
d) Commode to bathtub transfer



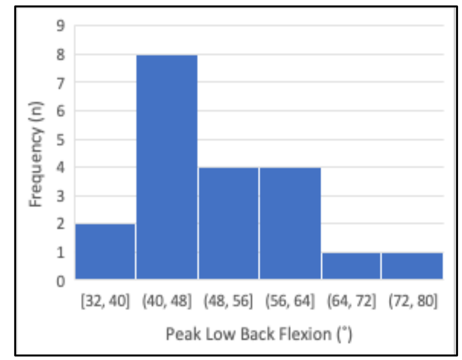
e) Commode to wheelchair transfer



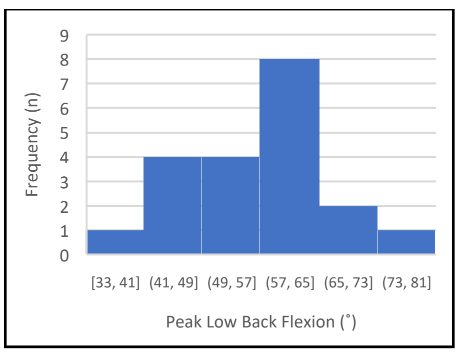
f) Dress



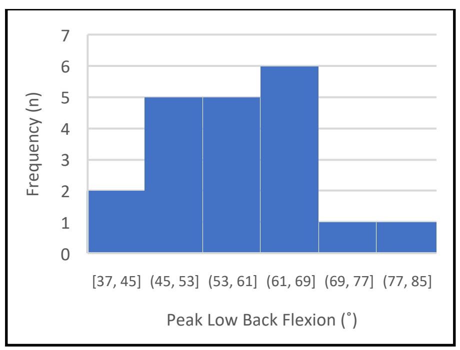
g) Reposition patient up the bed



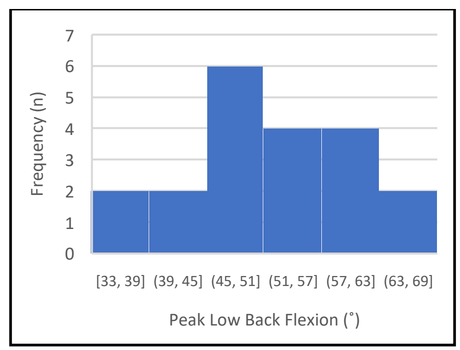
h) Apply comp. stockings (bed)



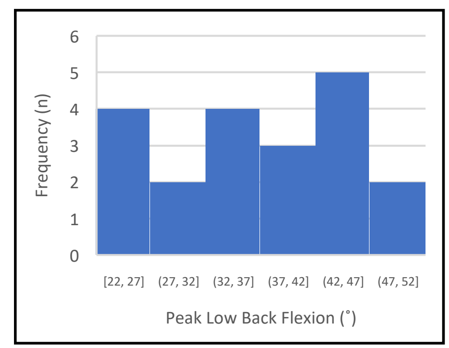
i) Apply comp. stockings (commode)



j) Undress



k) Wheelchair to bed transfer

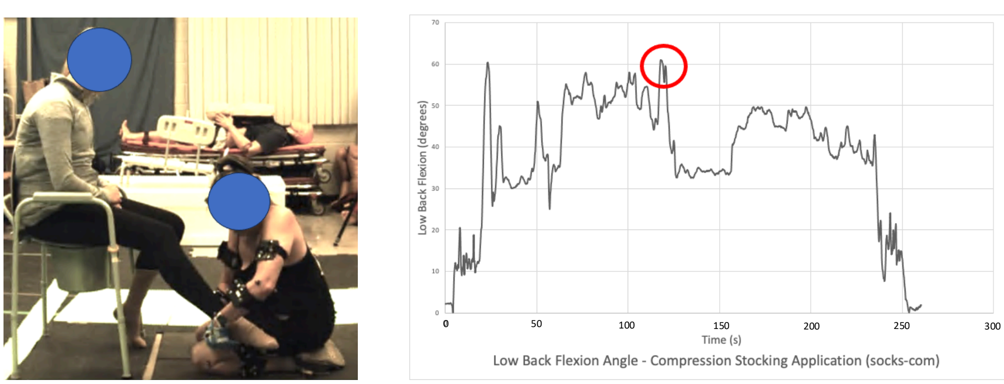


l) Wheelchair to commode transfer

The APDFs showcased that the probability at which certain levels of flexion occurred varies across the different tasks (Figure 18). Compression stocking application, whether the patient was lying down in bed or sitting on the commode, had a higher probability of participants adopting moderate to severe flexion in comparison to other tasks. When applying stockings on a patient who was in bed, participants were in mild flexion about 30% of the time and spent the rest of the time in either moderately or severely flexed postures. Similarly, participants engaged in mild flexion 20% of the time and moderate to severe posture for the rest when applying stockings on a patient sitting on a commode. In contrast, during transfers between the commode and wheelchair, participants were more likely to adopt mildly flexed postures (com-wc 65%; wc-com 65%). All other tasks had approximately a 45-50% probability of the participant being in a mild posture. Within the APDFs, variability can be seen across the plots as well, with the standard deviation amongst participants shown for each degree of flexion. It can be observed that for most tasks, the standard deviation is larger within the moderate flexion range and tapers off at both ends of the extreme, across most tasks. Some tasks appear to have more variability within the severe flexion range, specifically both compression stocking application tasks.

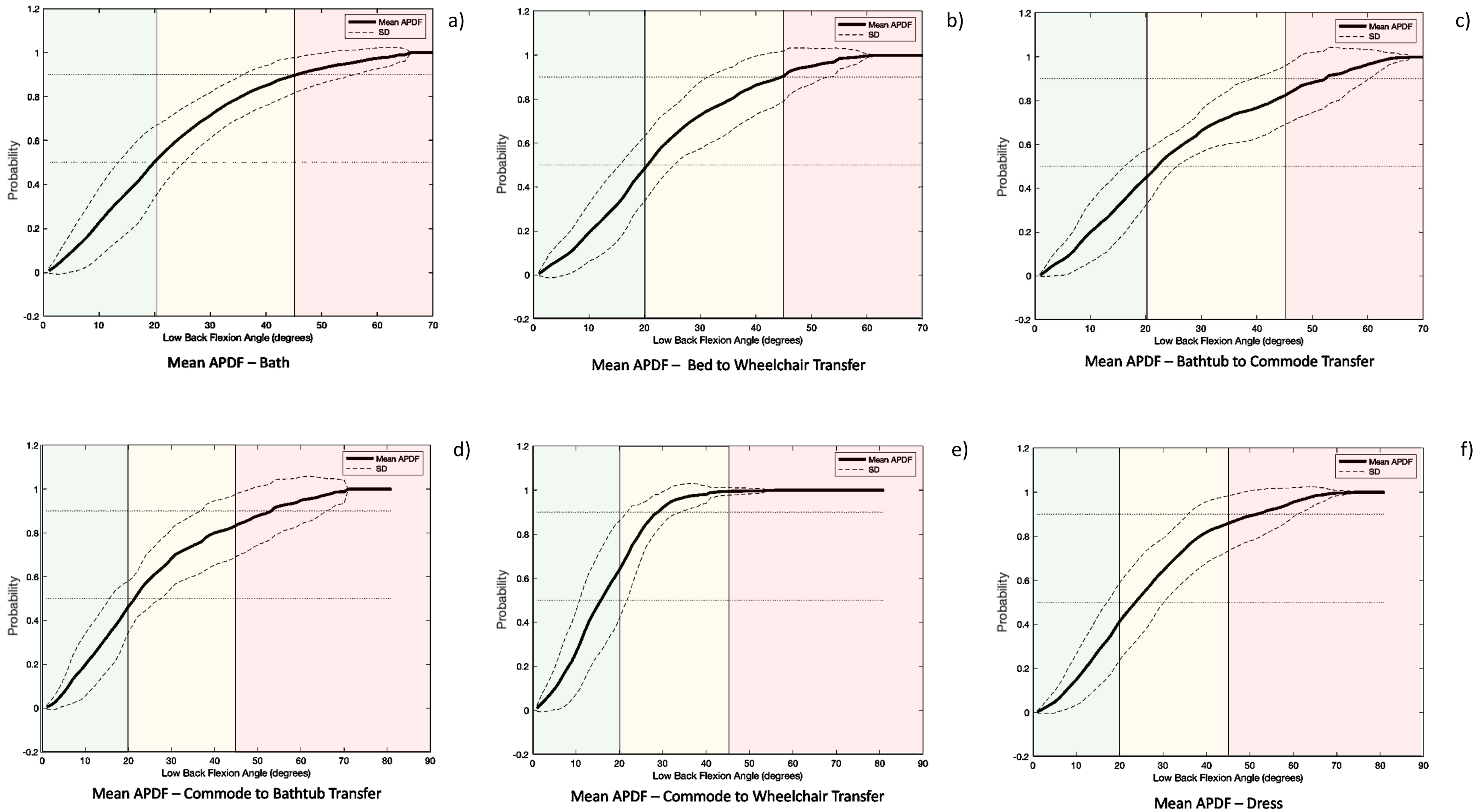
For transfer tasks, peak low back flexion typically occurred when assisting the patient to stand from the initial location as well when assisting the patient to sit down. (Table 10). With transfers between the bed and wheelchair, adjustment of the wheelchair such as applying/disengaging the brakes or adjusting the footrests and adjustment of the bed also produced peak low back flexion. For other tasks, when there was a requirement for the participant to work near the patient's legs or feet, higher low back flexion occurred. For example, peaks were observed when performing lower leg/foot care during the bathing task or when putting compression stockings on a patient sat on the commode (Figure 17). When repositioning the patient, peak flexion occurred when adjusting the slider sheet underneath the patient and when pulling the patient up the bed.

Figure 17. *A participant applying compression stockings to patient while patient is sat on the commode.*



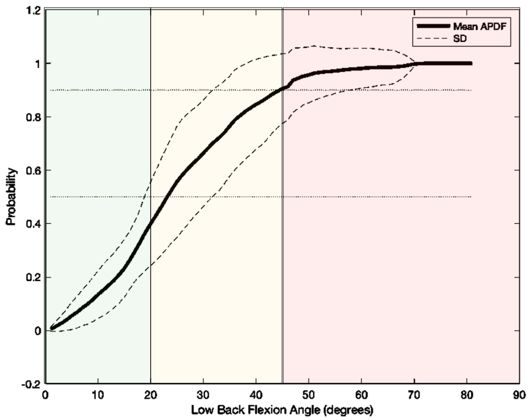
Note. Picture of the participant pulling the stocking up patient's leg (left) and the degree of flexion and the corresponding time-series low back flexion data (right). The red circle identifies the point in time captured in the participant photo.

Figure 18a-l. *APDFs (average of APDFs for all participants) for peak low back flexion (degrees) across all tasks.*



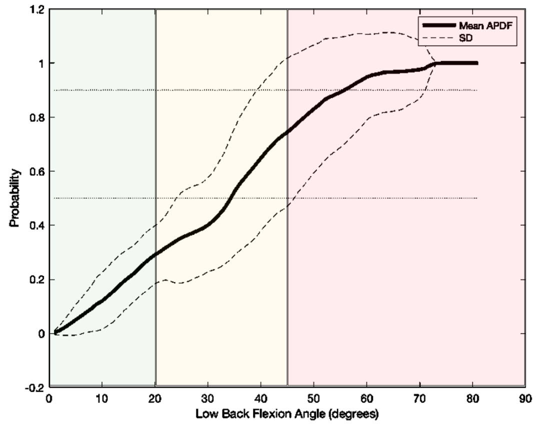
Note. Shaded green areas represents mild flexion (0-25 degrees), yellow represents moderate flexion (25-45 degrees), and red represents severe flexion (>45 degrees). Horizontal dotted line represents the 50th and 90th percentile.

g)



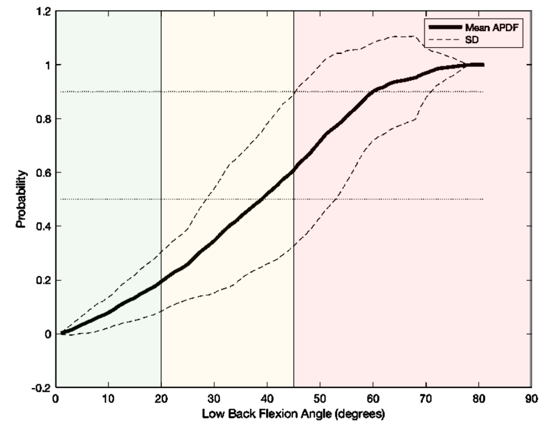
Mean APDF – Repositioning patient up the bed

h)



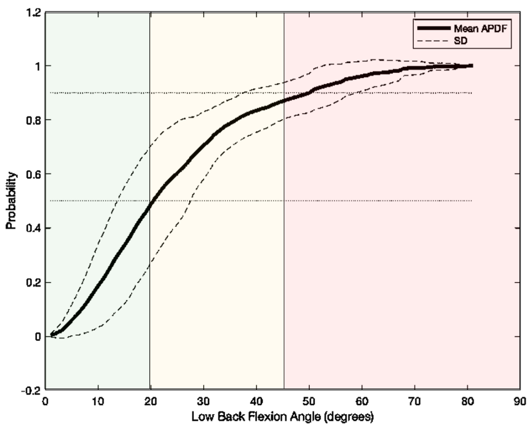
Mean APDF – Compression stocking application (bed)

i)



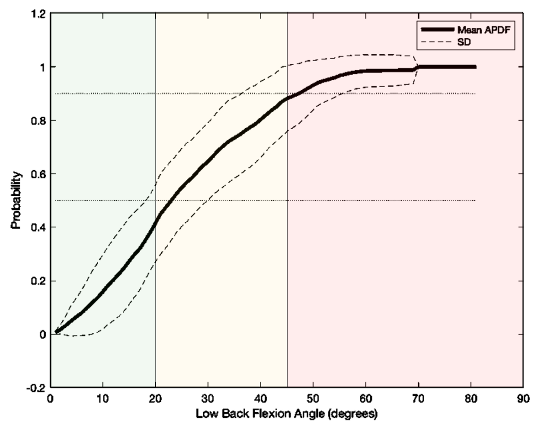
Mean APDF – Compression stocking application (commode)

j)



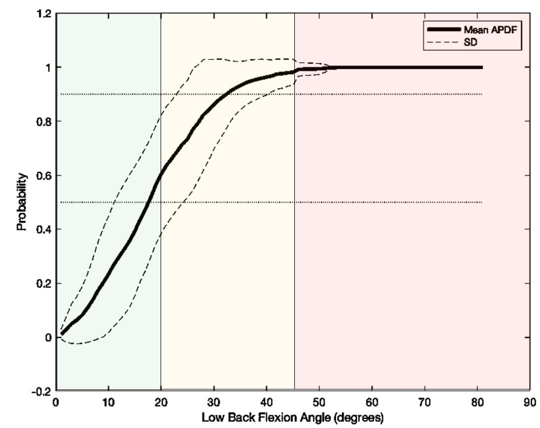
Mean APDF – Undress

k)



Mean APDF – Wheelchair to Bed Transfer

l)



Mean APDF – Wheelchair to Commode Transfer

Note. Shaded green areas represents mild flexion (0-25 degrees), yellow represents moderate flexion (25-45 degrees), and red represents severe flexion (>45 degrees). Horizontal dotted line represents the 50th and 90th percentile.

Table 10. *The action within the task where peak low back flexion and extensor moment occurred.*

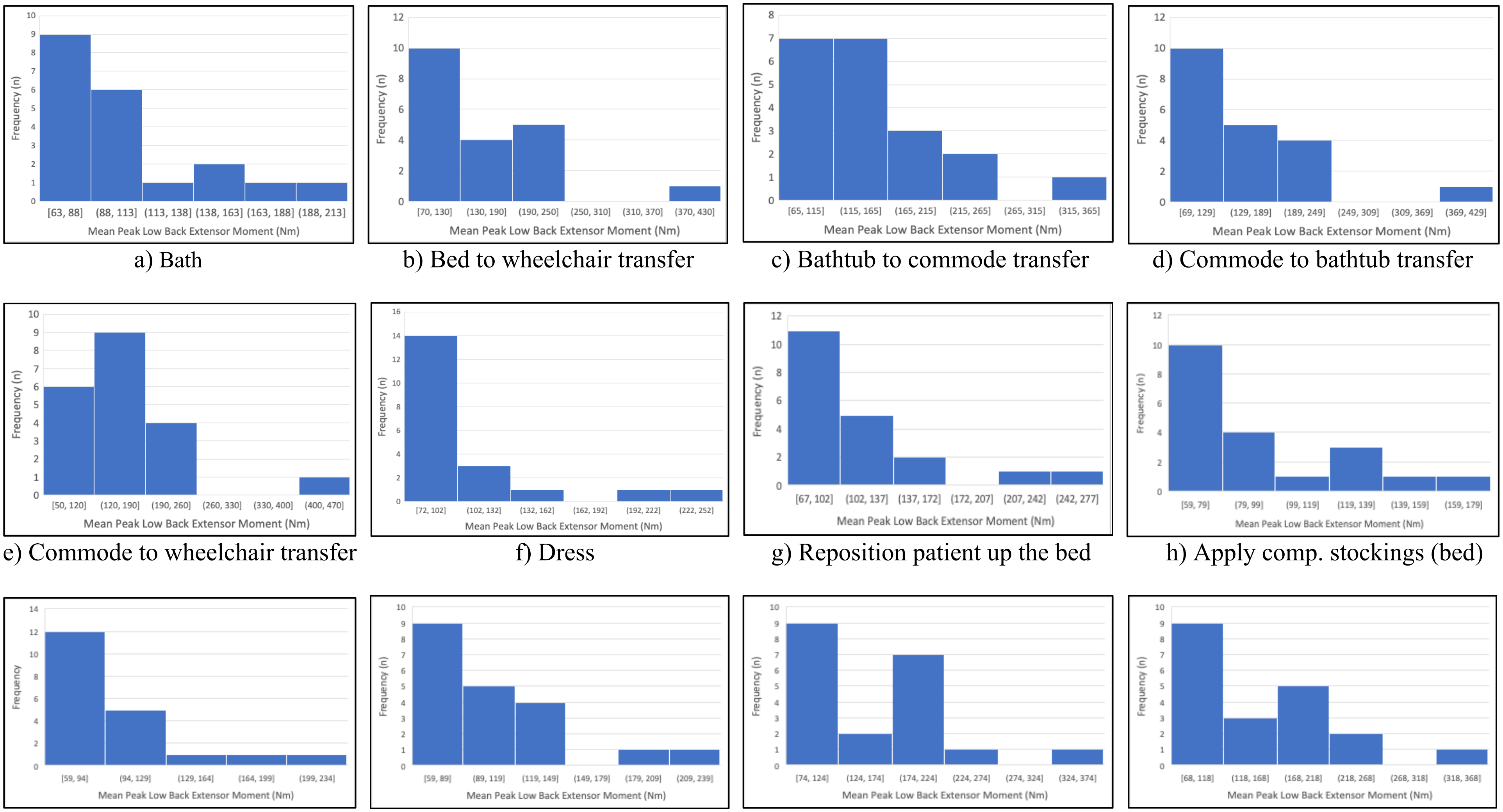
Task	Peak Flexion	Peak Extensor Moment
bath	• Lower leg and feet care • Perineal care	Lower leg and feet care Perineal care
bed-wc	• Adjustment of wheelchair (e.g., footrests, applying brakes) • Lifting the top of the bed up • Lifting patient's legs to rotate patient • Assisting the patient to stand from bed	Assisting the patient to stand from bed
bt-com	• Lifting patient's legs out of bathtub	Assisting the patient to stand from bathtub chair
com-bt	• Lifting patient's legs into bathtub	Assisting the patient to stand from commode
com-wc	• Assisting the patient to stand from commode • Assisting the patient to sit on wheelchair	Assisting the patient to stand from commode
dress	• Pulling pants up the patient's legs	Pulling pants up the patient's legs
repost-bed	• Sliding sheet underneath patient • Pulling patient up the bed using the slider sheet	Rolling patient towards themselves
socks-bed	• Pulling socks up patient's legs	Pulling socks up patient's legs
socks-com	• Pulling socks up patient's legs	Pulling socks up patient's legs
undress	• Pulling pants down the patient's legs	Pulling pants down the patient's legs
wc-bed	• Adjustment of wheelchair (e.g., pulling wheelchair closer to bed, applying brakes) • Lowering the top of the bed up • Lifting patient's legs onto bed • Assisting the patient to stand from wheelchair	Assisting the patient to stand from wheelchair
wc-com	• Assisting the patient to stand from wheelchair • Assisting the patient to sit on commode	Assisting the patient to stand from wheelchair

4.2.3. Low Back Extensor Moment

Sample mean peak low back extensor moment ranged from 92.7 Nm to 156.1 Nm across all tasks, with the highest extensor moments found during wheelchair to commode as well as wheelchair to bed transfers (Table 9). As well, the transfer tasks, overall, had the highest mean extensor moments. In contrast, lower sample mean peak moments were present when participants were applying compression stockings to the patient (socks-bed 92.7 ± 31.3 Nm ; socks-com 98.6 ± 42.9 Nm). Tasks that had higher sample mean peak extensor moments had larger standard deviations, with the transfer task standard deviations spanning from 66 to 87 Nm. Other tasks that had lower sample mean peak moments had standard deviations ranging from around 30 to 45 Nm. Between participant, within tasks, variability was evident. Similar to the ranges report for low back flexion, the range differences were greater for tasks that had higher mean extensor moments (approximately 250 to 400 Nm) while smaller range differences for tasks with lower mean moments (approximately 100 to 200 Nm). The distribution of peak extensor moments across the tasks are shown in Figure 19.

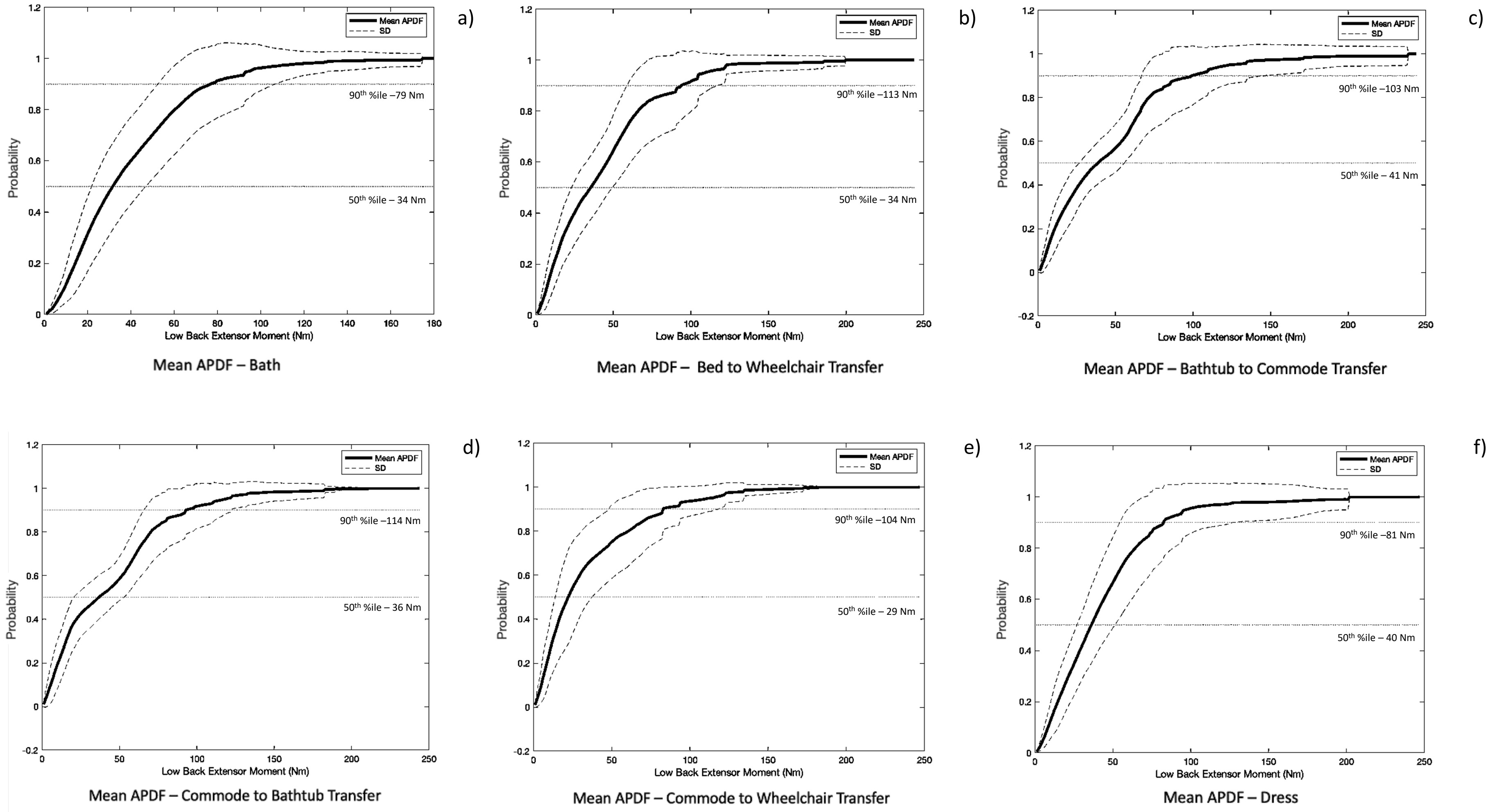
The APDFs show that patient transfers had higher extensor moments at a 90th percentile compared to other tasks (ranging from 96 -114 Nm) (Figure 20). However, these tasks had lower magnitudes of extensor moments, ranging from 26 to 41 Nm, at the 50th percentile. In contrasts, tasks such as patient bathing and the application of compression stockings had lower extensor moment values at the 90th percentile (bath 79 Nm; socks-bed 76 Nm; socks-commode 82 Nm) but had higher extensor moments at the 50th percentile (bath 34 Nm; socks-bed 57 Nm; socks-commode 60 Nm). Within the APDFs, variability was largest within the mid-range of extensor moment values for most tasks. Higher variability is apparent in the bathing task and both compression stocking application tasks, while lower standard deviation can be seen for tasks such as the patient transfer.

Figure 19a-l. *Frequency histograms for mean peak low back extensor moment (Nm) across all tasks.*

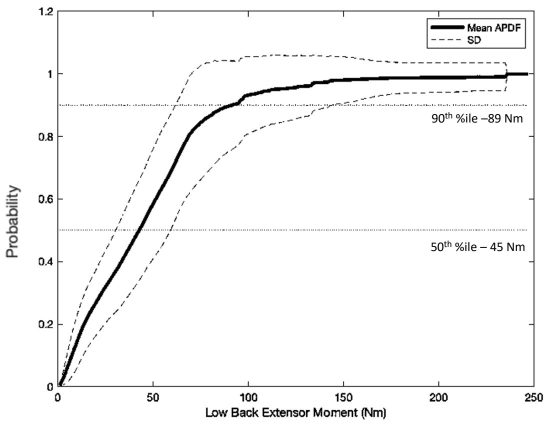


a) Bath
b) Bed to wheelchair transfer
c) Bathtub to commode transfer
d) Commode to bathtub transfer
e) Commode to wheelchair transfer
f) Dress
g) Reposition patient up the bed
h) Apply comp. stockings (bed)
i) Apply comp. stockings (commode)
j) Undress
k) Wheelchair to bed transfer
l) Wheelchair to commode transfer

Figure 20a-l. *APDFs (average of APDFs for all participants) for peak low back extensor moment (Nm) across all tasks.*

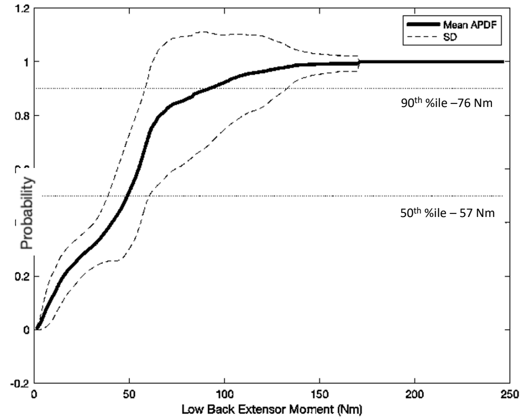


Note. Horizontal dotted line represents the 50th and 90th percentile and the associated extensor moment values are provided.



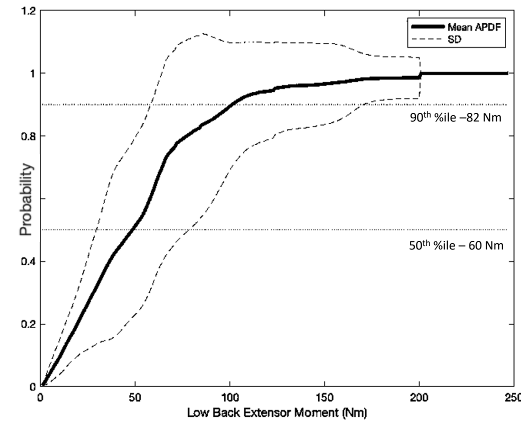
g)

Mean APDF – Repositioning patient up the bed



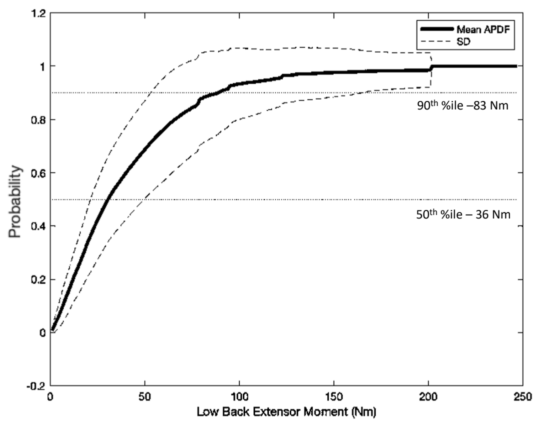
h)

Mean APDF – Compression stocking application (bed)



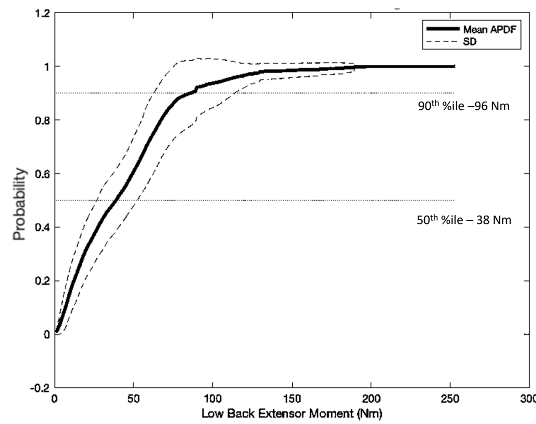
i)

Mean APDF – Compression stocking application (commode)



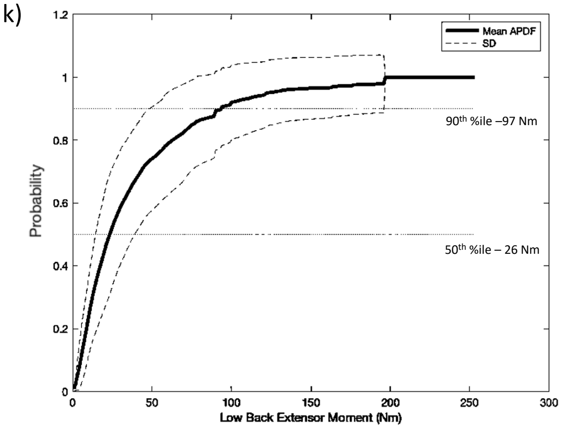
j)

Mean APDF – Undress



k)

Mean APDF – Wheelchair to Bed Transfer



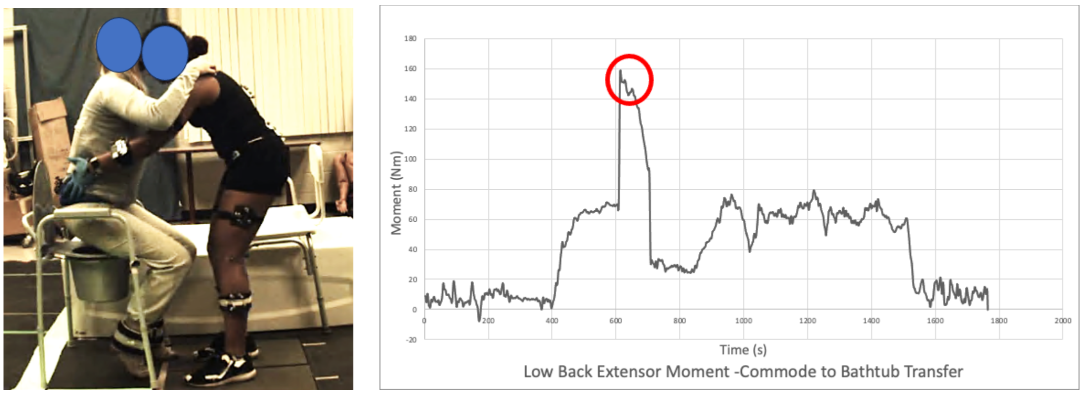
l)

Mean APDF – Wheelchair to Commode Transfer

Note. Horizontal dotted line represents the 50th and 90th percentile and the associated extensor moment values are provided.

For transfer tasks, peak low back extensor moment occurred when assisting the patient to stand from the initial posture (Table 10 and Figure 21). For other tasks, similar to peak low back flexion, peak extensor moments when there was a requirement for the participant to work near the patient's legs or feet. When repositioning the patient up the bed, peak extensor moments typically occurred when the participant rolled the patient towards themselves.

Figure 21. *A participant transferring the patient from the commode to bathtub.*

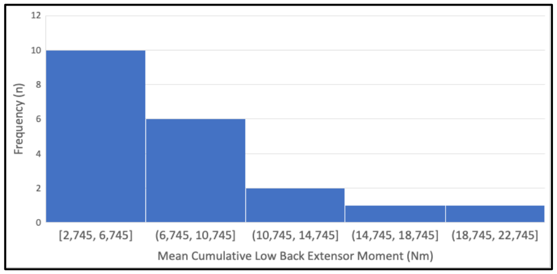


Note. Picture of the participant assisting the patient in standing from the commode(left) and the corresponding time-series low back extensor moment data (right). The red circle identifies the point in time captured in the participant photo.

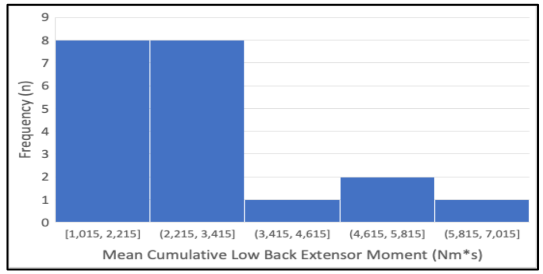
4.2.4. Cumulative Extensor Moment

The highest cumulative extensor moment values were found during the patient bathing task (8008.6 ± 4716.3 Nm*s) and the task of applying compression stockings (socks-bed 5863.3 ± 3168.2 Nm*s; socks-com 5863.3 ± 2283.3 Nm*s). Lower cumulative extensor moment values were found for transfers between the wheelchair and commode (com-wc 1329.3 ± 916.7 Nm*s; wc-com 1502.3 ± 1348.2 Nm*s) and undressing the patient (2623.0 ± 1268.1 Nm*s). Variability across the tasks is evident, as mean cumulative extensor moments ranged from 2623.0 Nm*s up to 8008.6 Nm*s across all tasks. Additionally, variability was also apparent between PSWs, within tasks, where tasks that had the highest cumulative extensor moments had the widest range. Tasks such as bathing, application of compression socks and patient dressing had range differences spanning from 10,000 to 18,000 Nm*s. The descriptive statistics can be found in Table 9 and the distribution of cumulative extensor moments for all the tasks are shown in Figure 22.

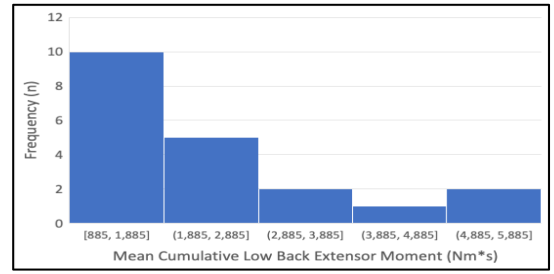
Figure 22a-l. *Frequency histograms for cumulative low back extensor moment (Nm*s) across all tasks.*



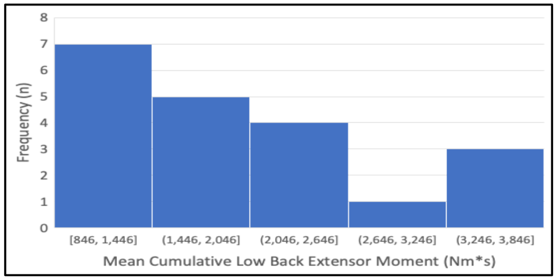
a) Bath



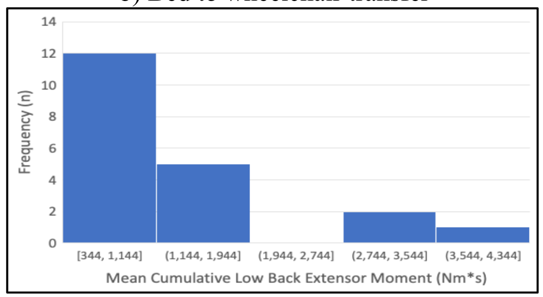
b) Bed to wheelchair transfer



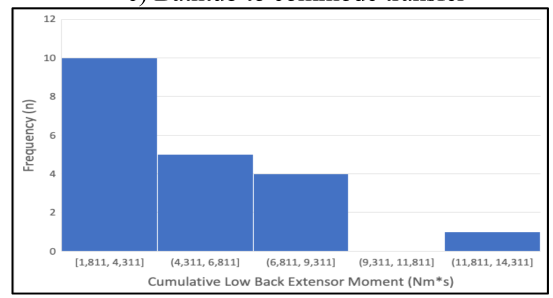
c) Bathtub to commode transfer



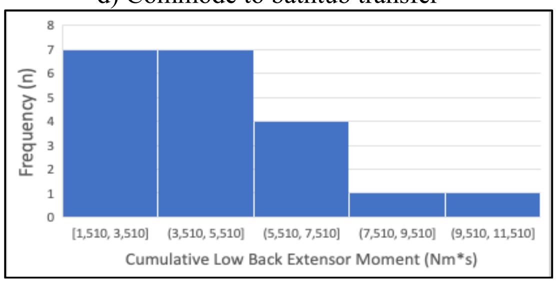
d) Commode to bathtub transfer



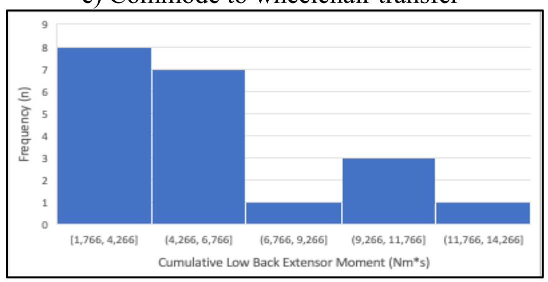
e) Commode to wheelchair transfer



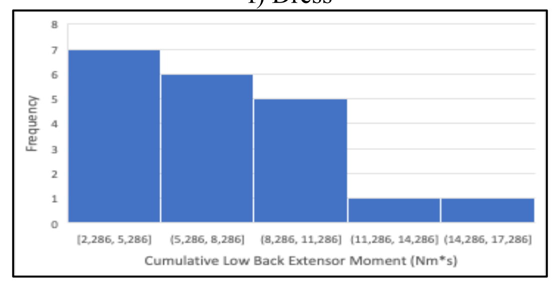
f) Dress



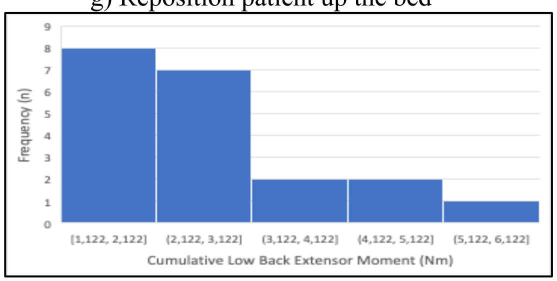
g) Reposition patient up the bed



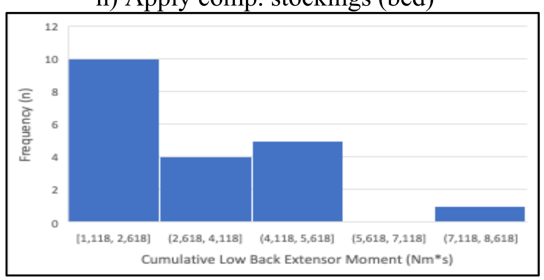
h) Apply comp. stockings (bed)



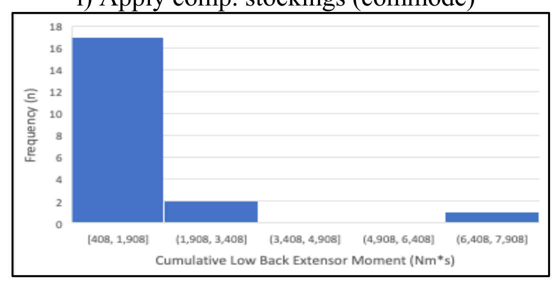
i) Apply comp. stockings (commode)



j) Undress



k) Wheelchair to bed transfer



l) Wheelchair to commode transfer

4.2.5. RPE Scores

Post-task RPE scores across all tasks had a mean and standard deviation of 11.4 ± 1.9, where a score of 11.4 corresponding to 'light' to 'somewhat hard' exertion levels (Table 11). Post-task RPE scores ranged from 7 to 17, with higher post-task RPE scores recorded for the task of dressing the patient (12.1 ± 2.3) and repositioning the patient up the bed (12.0 ± 2.3). Pre-task RPE scores averaged around 8.2, indicating that participants were under 'extremely light' to 'light 'exertional levels at the initiation of each task.

Table 11. *The mean of pre-task RPE scores in addition to the mean, standard deviation (SD), and range for post-task RPE scores for each task.*

	Pre-task RPE Scores	Post-task RPE Scores			
				Range	
Task	Mean	Mean	SD (±)	Low	High
dress	8.7	12.2	2.3	7	16
repost-bed	8.2	12.0	2.3	8	17
socks-bed	7.8	11.9	2.2	9	16
bath	8.1	11.7	1.8	8	15
socks-com	8.5	11.7	2.2	8	15
bed-wc	8.4	11.3	1.8	8	14
wc-bed	8.3	11.2	1.5	8	13
wc-com	8.1	11.1	1.7	8	14
com-bt	8.4	11.0	1.8	8	14
bt-com	8.2	10.9	1.7	8	14
com-wc	8.1	10.7	1.9	7	14
undress	8.3	10.6	2.1	7	14
All tasks	8.2	11.4	1.9	7	17

Note: Scores scale from 6-20 (Borg, 1971).

4.3. Relationship Between Subjective and Objective Exposure Metrics

Linear regression analyses were used to examine the relationship between post-task RPE scores and the following objective exposure metrics for each participant: peak low back flexion angle, peak low back extensor moment, and cumulative low back extensor moment. Within each exposure metric, participants were ranked from highest to lowest correlation coefficient (R) to examine the strength of the relationship between RPE and the exposure metrics across participants (Table 12). Additionally, scatterplots were created showcasing participant-specific linear regression slopes for each exposure metrics (Appendix H).

Table 12. *Linear regression analyses – Rank order of participants, ranked from highest to lowest correlation coefficient (R) value.*

Peak Flexion Angle		Peak Extensor Moment		Cumulative Extensor Moment	
Participant	R	Participant	R	Participant	R
P05	0.75	P01	0.51	P15	0.98
P10	0.66	P17	0.39	P17	0.97
P18	0.58	P19	0.22	P19	0.97
P12	0.53	P04	0.20	P18	0.97
P02	0.47	P08	0.15	P14	0.96
P01	0.36	P20	0.04	P16	0.92
P09	0.32	P11	0.03	P20	0.75
P13	0.24	P05	0.02	P13	0.62
P16	0.12	P06	-0.10	P07	0.58
P07	0.11	P18	-0.11	P05	0.56
P11	0.11	P14	-0.23	P03	0.56
P08	0.08	P07	-0.28	P12	0.55
P04	0.01	P09	-0.32	P01	0.53
P20	-0.02	P03	-0.37	P09	0.49
P03	-0.06	P15	-0.41	P02	0.48
P17	-0.10	P10	-0.44	P11	0.44
P19	-0.11	P13	-0.45	P10	0.34
P15	-0.15	P02	-0.50	P06	0.24
P14	-0.25	P16	-0.53	P04	0.16
P06	-0.56	P12	-0.55	P08	<0.001

Mean R, mean coefficient of determination (R^2) and 95% confidence intervals were calculated across participants (Table 13). A significant moderate (0.4-0.69) positive relationship was found between RPE and cumulative extensor moment with a mean R of 0.6 and around 45% of the variance in cumulative extensor moment being explained by RPE. The relationship between RPE and the peak exposure metrics were both found to be non-significant and very weak (0.01-0.39). Correlation coefficients were classified as per suggestions by Moore et al. (2013).

Table 13. *Linear regression analyses - Mean statistical measures across participants.*

	Peak flexion angle	Peak extensor moment	Cumulative extensor moment
R	0.155	-0.13	*0.6
R^2	0.131	0.116	0.446
95% CI	0.0085 - 0.3019	-0.2760 - 0.0041	0.4754 - 0.7321

Note. Mean coefficient correlation (R), mean coefficient of determination (R2) and 95% confidence intervals (CI) calculated across all participants. Significance indicated by '*' ($p<0.05$).

A Pearson correlation matrix was conducted to evaluate the relationship between low back exposure metrics, namely, peak flexion, peak extensor moment and cumulative extensor moment (Table 13). A significant correlation was found between peak flexion and peak extensor moment. No other pairings were significant.

Table 14. *Correlation matrix for low back exposure metrics.*

Exposure Metric	Peak flexion	Peak extensor moment	Cumulative extensor moment
Peak flexion			
Peak extensor moment	* -0.141		
Cumulative extensor moment	0.111	0.083	

Note. * represented significance ($p<0.05$).

4.4. External Validity

From the post-collection survey, participants were asked to rank how similar the work tasks they completed within the study were to tasks that they completed in their real work (Appendix G). From a scale of 1 to 10, 1 being not realistic at all, and 10 being exactly the same, an average score of 8.6 (± 1.2) was found, with a range of between 6 to 10.

5.0. Discussion

5.1. Demographics and General Work Characteristics

Before proceeding with the analysis of the study's biomechanical outcomes, it is important to provide context for the subsequent discussion and consider characteristics of the worker population of interest. The participants comprised 85% females and 15% males, with an average age of 43 years. The sample from this study is reflective of the PSW population, as a majority of PSW workers are middle-aged females (Alamgir et al., 2007; Lum et al., 2015; Zagrodney et al., 2022). Specifically, Zagrodney et al. (2022) provided some of the most recent statistics regarding PSWs working in Canada, with approximately 84-88% of PSWs working in LTC and home care being female and having an average age of around 41-43 years of age.

Regarding work-related characteristics, PSWs attend to a considerable number of patients both on a daily and weekly basis. Specifically, the participants, on average, attended to six patients per day and 29 patients per week. It is noteworthy that there was extensive variability in the number of patients attended to among the participants, with the highest number being 18 patients per day and 120 patients per week. Conversely, some participants reported attending to only a few patients per day, the lowest being one patient per day. Moreover, in terms of working hours, the participants generally worked full-time hours, with an average of seven hours per day and 38 hours per week. Variability was also present in working hours across participants. Some PSWs worked only a few hours a day and up to 17 hours a week, while other worked up to 12 hours a day and 72 hours a week. Referring to prior literature that characterized PSW work, it is largely agreed upon that PSW work is extremely varied in terms of workload, in terms of both frequency and magnitude. whether that be patient-to-patient or day-by-day (Garg et al., 1992). However, data about the frequency of and variability in patient visits and working hours also reinforces the potential for implementing a workload management strategy to optimize the balance in patient visits on a daily or weekly basis or hours worked per day.

5.2. Distribution of Biomechanical Exposure Metrics

By characterizing exposure metrics including peak flexion, peak extensor moment and cumulative extensor moment, trends were identified that may inform future hypothesis testing, and/or intervention. As an example, peak and cumulative extensor moment (Figure 19 & 22) distributions were skewed for many tasks, with long tails present towards higher extensor moments. Therefore, it appears that a few participants were found to experience much higher peak and cumulative moments in comparison to the rest. From an injury prevention standpoint, it may be useful to understand why a subset of individuals seem to experience higher exposures than their counterparts.

To further understand potential sources of the skewedness, a deeper dive into the data was conducted. The participants who possessed exposure metrics that were higher than others were identified (Table 15). Consistently, two participants had high peak extensor moments across all the tasks. The demographics of these participants were examined; one participant (P15) was female, 1.78m tall and weighed 127kg and the other participant (P17) was male, 1.80m tall and weighed 122kg. These anthropometrics likely explain why these participants experienced higher peak moments in comparison to other participants, as both individuals were taller and heavier than other participants in the sample. As for cumulative extensor moment, the skewedness of the data is likely due to variability in the amount of time participants spent to complete the task. There were no restrictions given regarding time, therefore participants had full control on the pace of their work. As such, it can be expected that although most participants would take a similar amount of time, especially for shorter tasks (e.g., transfer tasks), there may be some individuals who spend more time completing a task. Again, it was examined across all tasks if specific participants consistently had higher cumulative moments. A subset of participants consistently had higher cumulative extensor moments. In addition, these participants also had unique demographics, where two of these participants were male (P03, P13). The other participant was female (P10), 1.65m tall, and weighed 100kg. Therefore, it appears that a subset of participants seemed to take longer completing all tasks and they possessed demographic characteristics (sex, height, weight) that were likely to be outside of the normal PSW population.

From this analysis, it appears that taller and heavier individuals experience higher peak moments in addition to higher cumulative moments. These higher loads may contribute to a higher risk for injury; however, it is important to note that taller and heavier individuals may also have higher musculoskeletal strength and have higher capacity to handle greater loads (e.g., higher mechanical advantage due to longer limbs). On the other hand, if these individuals are not conditioned properly (e.g., have enough strength, cardiovascular endurance, balance, etc.), these increased loads may put them at higher risk for injury. Therefore, it is important to take into consideration individual's unique capacity and internal thresholds when evaluating how task exposures can affect risk of injury.

Table 15. *The mean moments across the participants in comparison to the participants identified to have high moment values.*

Task	Peak Extensor Moment (Nm)			Cumulative Extensor Moment (Nm*s)			
	Mean	P15	P17	Mean	P03	P10	P13
bath	105.2	179.3	196.5	8008.6	12966.6	10429.45	16907.2
bed-wc	153.8	202.4	378.2	2824.2	5398.8	5466.2	4302.6
bt-com	148.1	219.2	343.6	2338.5	4224.6	3079.5	5578.1
com-bt	150.1	219.8	421.1	1943.9	3375	2760.7	3802.9
com-wc	150.2	223.1	447.7	1329.3	2908.6	1668.6	3670.6
dress	105.5	233.4	204.4	4971.1	6667.45	8898.5	11825.2
repost-bed	115.3	219.6	258.7	4552.3	8112.3	5812.3	6137.7
socks-bed	92.7	139.5	173.4	5863.3	10213.6	9968.9	6069
socks-com	98.6	188.7	213.8	6719.1	8872	16278.2	11754.3
undress	106	189.3	211.7	2623	3385.6	4672.1	5759
wc-bed	155.2	229	353.1	3112.5	3886	4865.4	5187.9
wc-com	156.1	236.8	328.4	1502.3	1817.9	2368.8	6493.9

5.3. Variability in Exposure Metrics Within Tasks

Variability between PSWs within tasks was evident across all metrics. Differences in participant demographics (height, weight) likely explain a portion of the within-task variability. However, the nature of each task is also a likely contributor. Tasks that had higher cumulative extensor moments seemed to be tasks that were not only longer on average in terms of task duration but were more complex in nature (e.g., bathing, dressing, undressing). These tasks have more intricate steps involved, which allowed for participants to engage in different techniques and ordering of actions, overall, having higher degrees of freedom in comparison to patient transfers or repositioning tasks. For example, with the task of applying compression stockings onto a patient sitting on the commode, some participants would stoop down to apply the stockings and others would kneel on the ground, which can cause differences in time duration and low back moments. In addition, it is important to acknowledge that participants may have rushed through the task, which King and colleagues (King et al., 2007; King et al., 2008) noted as a challenge when PSW tasks performance is actively measured. The future ability to measure and monitor exposure metrics in real-time, may support more detailed analysis to identify optimal techniques (those on the lower end of the distribution) that can be used to inform future training.

5.4. Evaluation of Exposure Metrics Across Tasks

5.4.1. Examination of Rank Order of Tasks by Exposure Metrics

When tasks were rank ordered from highest to lowest based on each exposure metric, patterns emerged that may inform research and interventions moving forward. Patient dressing/undressing, application of compression stockings (socks-com) and bathing tasks ranked highest, with respect to peak flexion. These tasks require the participants to complete some type of care with the patient's feet and legs, which is likely the reason behind the higher values. For example, when bathing a patient, as participants were instructed to provide a full body wash for the patient, participants were required to do feet care which required the participants to reach deep into the bathtub. Additionally, select transfers also ranked higher with respect to peak flexion angle and involved interactions between the participant and then patient's legs. During transfers between the commode and bathtub (com-bt, bt-com) and between the bed and wheelchair (bed-wc, wc-bed), the participant is required to lift the patient's legs in/out of the bathtub and to lift the patient's legs onto/off the bed, respectively. One exception was the compression stocking application when the patient was in bed which ranked lower, although the participant is required to interact with the patient's feet/legs for long periods of time. This, however, is reasonable as the bed was at a relatively high height, putting the patient's feet at about waist level for most participants and requiring less bending to complete the tasks.

Overall, these findings are agreeable to data from Garg and Owen (1992), where mean flexion exceeded 30 degrees for most transfer tasks and exceeded 50 degrees for bathing and dressing/undressing tasks. As well, an average flexion of around 45-75 degrees was found by King et al. (2019) when removing and re-dressing the patient's pants (as a part of the toileting procedure), which is comparable the results from this study. As for patient bathing, King et al. (2020) found that PSWs engaged in mild flexion (20-45 degrees) for 22% of the task and severe flexion (>45 degrees) for 21% of the task. In this study, participants adopted mildly flexed posture for 50% of the task and around 10% of the task is spent in more than 45 degrees flexion, which is similar to the results achieved in this study. Similarities between these data and previous data add confidence about the validity of the data captured in this study. Additionally, the data highlight that posture specific risks are task dependent.

Regarding mean peak and cumulative extensor moments, it was observed that tasks ranked lower based on mean peak moments (e.g., compression stocking application, bathing) often ranked higher based on mean cumulative moments, and vice-versa. The APDFs reinforce this interpretation where patient transfer and repositioning tasks had higher probabilities of lower extensor moment values (26 to 41 Nm at the 50th percentile) and lower probabilities of higher extensor moment values (89 to 114 Nm at the 90th percentile). In contrast, tasks such as patient bathing, dressing and undressing, and the application of compression stockings had lower extensor moment values at the 90th percentile (76 to 83 Nm) but had higher extensor moments at the 50th percentile (34 to 60 Nm). From these results, it is clear that different work tasks expose PSWs to different loading scenarios, where some tasks imposing short periods of higher magnitude loading (patient transfer and repositioning tasks) whereas other tasks impose longer periods of repetitive or sustained low to moderate loads (patient care tasks such bathing or dressing). These differences may have important implications in terms of plausible injury pathways and associated intervention strategies.

5.4.2. Task Specific Injury Profiles and Plausible Injury Mechanisms

Regarding known injury mechanisms within an occupational context, two pathways have been identified to be the most commonly occurring: acute and cumulative. Acute injuries occur during singular event, where a worker is put under a high load that exceeds this individual's internal tolerance, leading to an injury such as fractures or sprains/strains (McGill, 1997; McGill, 2007). Typically, these injuries come as a result of the individual handling an external load which requires forceful exertions, putting them under high levels of biomechanical loading within the body (e.g., compressive forces on the spine). With an acute injury being an outcome of this mechanism, within literature, a large amount of focus has been placed on characterizing and quantifying the biomechanical exposures that are associated with work tasks that possess a similar injury profile (e.g., acute trauma) and are likely to follow this model of injury.

Patient handling tasks are largely considered to induce short period of high loads upon patient handlers and have a high risk of injury (Galinsky et al., 2001; Garg & Owen, 1992; Jang et al., 2001; Marras et al., 1999). Additional to the heavy external loads these healthcare workers are required to handle, frequently these workers must complete these transfers in cramped environments, forcing the adoption of awkward postures (Galinsky et al., 2001). Several studies have quantified the biomechanical loads associated with different transfer tasks performed by patient handlers (e.g., nurses, nursing assistants, etc.), and the compression values exceeded NISOH action limits, even with a lighter patient (Daynard et al., 2001; Garg & Owen, 1992; Marras et a., 1995). Moment values were also identified to be high during transfer, ranging from around 100-200 Nm (Garg & Owen. 1992; Holmes et al., 2010; Jang et al, 2001). The results from this study are agreeable to past work completed, with tasks that require the manual transferring or repositioning of a patient resulting in high peak moment values and high levels of low back flexion. Specifically transfers where the wheelchair was the initial position ranked the highest in terms of peak extensor moment, including transfers from the wheelchair to the commode and from the wheelchair to the bed. Reasoning behind this may be the fact that the wheelchair seat height was lower that all other fixtures (e.g., bed, bathtub chair, commode), which requires participants to exert more force to lift the patient a greater distance to get them standing, aligning with previous literature (Garg et al., 1991).

In contrast, the cumulative trauma model describes the development of chronic conditions that arise as a result of accumulated damage to the tissues over a longer period of time. This model assumes that damage is accumulated due to repetitive or sustained loading of the tissues, where the internal tolerance can decline, such that a submaximal exposure can exceed the reduced internal tolerance (Brinckmann et al., 1988; Kumar, 1990; Kumar, 2001; Radwin et al., 2001). Tasks such as patient bathing, dressing, and feeding have been identified as performed most frequently and for a sustained amount of time. As well, these tasks require more moderate magnitudes of force in comparison to patient transfers. As such, when considering injury risks, these tasks might be better considered through the lens of cumulative load theory to better understand risks and controls where warranted.

Holmes and colleagues (1999) assessed peak and cumulative spinal loading amongst nurses working in a hospital and found that while patient handling produced peak spine loads, patient care tasks such as bathing, dressing, and feeding produced low spine forces. However, these tasks were performed the most frequently and contributed to the highest portion of overall shift time. Therefore, these tasks resulted in the highest cumulative load. Findings from this thesis are consistent with the conclusion of Holmes et al., (1999). Patient care tasks also require the caretaker to engage in awkward postures, where high degrees of flexion for extended period of time is necessary (Garg and Owen, 1992; King et al., 2018; King et al., 2020). Although limited research characterizes exposures associated with the application of compression stockings, Jang and colleagues (2007) found that applying compression stockings on a patient required a high degree of low back flexion, but yielded compressive forces that were lower than the NIOSH action limit (approximately 1610 N). Again, findings from this thesis were consistent with past literature where bathing, dressing, undressing and compression stocking application (socks-bed, socks-com) were the most frequently completed by the participants in this study (Table 7) and had the longest time durations (Table 8). Additionally, the present study calculated peak extensor moments that were lower than the transfer tasks by approximately 50 Nm and high levels of flexion were found at higher frequencies compared to transfer tasks.

From the results of this study and past literature, it appears that it might be useful to consider risk differently depending on the task. When evaluating risk associated with patient handling tasks, risk assessment and mitigation strategies might best align with the assessment and mitigate of acute injury. In contrast, when considering risk assessment and mitigation strategies for patient care tasks such as bathing or dressing might it might be best to align with cumulative load theory. As well, results from this study suggests that with the design or development of any ergonomic intervention or workload management system, that task specific loading profiles should be considered. Norman et al. (1998) echo similar sentiment as peak and cumulative loading are independent risk factors for low back disorders, and therefore, ergonomic interventions should cater towards the specific injury pathways that are best aligned with the time-series exposure patterns that observed. It is also important to consider the reality of PSW work, which is that a combination of tasks with varying exposure profiles are completed regularly, which means that the different exposure profiled may interact and affect one another. With PSWs performing tasks that may impose cumulative loading and sustained stress on the tissues, fatigue may develop with the tissues, making the worker more vulnerable to tasks such as transfers, which impose high loads that can exceed the individual's internal tolerance and lead to injury. While this comment is speculative, these findings further underscore the potential for a workload management-like solution to best optimize the time-series distribution of loading given how the different tasks are likely to alter tissue tolerance in different ways.

5.5. Perceived Exertion Scores

Mean post-task RPE scores across all the tasks were very similar, ranging from approximately 10 to 12 on the Borg 6-20 RPE scale, indicating that participants found the tasks to be 'light' to 'somewhat hard'. Other studies conducted that examined perceived exertion for similar tasks had some variation in responses. Garg et al. (1992) had health aides score tasks using the 6-20 Borg scale and found that transfer task scored around 13-14, repositioning a patient in bed at 12 and undressing a patient at 10. In contrast, Owen and Staehler (2003) examined nursing aides in home care who rated bathing as requiring a very high level of exertion, with a mean score of 8.2 on a 10-point Borg scale, representing 'extremely heavy exertion'. Overall, it seems that our post-task RPE scores are relatively low across all tasks, especially when compared to the objective exposure metrics that were calculated. The characteristics of the live-actor patient used in this study may explain why the RPE values in this study were lower than in previous studies. It is possible that the patient, although acting with lower functional abilities and being of heavier weight and being tall, that they were deemed to be fairly easy to work with by the patient, leading to lower RPE scores.

5.6. Relationships Between Perceived Exertion and Objective Exposure Metrics

Results from the regression analysis indicated a significant moderate (0.4-0.69) positive association between RPE and cumulative low back extensor moment for each participant. Additionally, the calculated confidence interval indicates 95% confidence that the correlation between RPE and cumulative extensor moment was between 0.475 to 0.732 for PSWs. It is thought that a stronger relationship between RPE and cumulative extensor moment was present since cumulative loading considers both the magnitude of the load as well as the time-aspect of the task. Time has a strong influence on individual's perception of exertion due to accumulated fatigue (Eston, 2009; Eston, 2012; Pandolf, 1978), which aligns better with cumulative load measures. Eston (2012) concluded that RPE progression is related to activity duration. This notion is strengthened when examining the post-task RPE scores (Table 11), which trended higher when it came to tasks such as bathing and compression stocking application, which were all tasks that had the highest task time durations along with the highest cumulative extensor moments.

In contrast, the relationship between RPE and the peak exposure metrics (flexion angle and extensor moment) were found to be non-significant and very weak. RPE is influenced by task duration, as previously stated, but other task characteristics such as magnitude of external loading are also pertinent to individual's perceived exertion. Results from the linear regression analyses suggests that PSWs may be more sensitive to cumulative biomechanical exposure metrics which considers both time and magnitude, rather than peak exposure metrics that does not include time duration. It is important to note that the peak exposure metrics calculated from the examined PSW work tasks were moderate in magnitude (Table 9), which may play a part in the weaker associations found in this study. With higher peak loads (e.g., if PSWs completed the examined work tasks with a heavier patient with extremely limited mobility), this may change how individuals perceive their level of exertion and the relationship between RPE and peak exposure metrics.

Prior research investigating the relationship between perceived exertion and peak low back exposure metrics presented with conflicting results. Garg et al. (1992) found that rating of perceived exertion scores (10-point Borg scale) and compressive spine forces had a correlation coefficient of 0.74 ($p < 0.05$) among nursing assistants completing a wide range of patient handling and care tasks, such as patient transfers and repositioning tasks, dressing/undressing the patient and making the bed. However, Skotte and colleagues (2002) who quantified compressive spine forces during patient handling tasks (e.g., transfers), did not find a correlation between RPE scores (using the 10-point Borg scale) and compression forces of the low back. Interestingly, Skotte et al. (2012) only studied patient handling tasks such as repositioning the patient on the bed and transfers. However, Winklemolen and colleagues (1994) looked at patient lifts using different techniques and found that mean peak low back flexion recorded at the start and end of lifts both correlated positively with RPE scores.

When examining the relationship between RPE and the exposure metrics, it appears that the strength in the relationships differs across participants. Some participants presented stronger relationships between RPE and peak flexion or peak extensor moment in comparison to RPE and cumulative extensor moment, and vice versa. For example, P05 had a strong positive relationship between RPE and peak flexion angle but a moderate positive relationship between RPE and cumulative extensor moment. This reinforces the sentiment that RPE is extremely participant-specific and that perceived exertion is dependent on individual factors (e.g., psychological, physiological) when the task is mostly controlled (Eston, 2012). Factors that influence cumulative extensor moment include participant anthropometrics (e.g., weight, height), as described in Section 5.2 and 5.3, with the variability in cumulative extensor moment likely being explained by the varying anthropometrics across the participants. In future investigations, exploring other factors that assists in explaining variance in cumulative extensor moment in a multiple regression model may provide a strong foundation for a workload management tool.

To summarize, there seems to be a relationship between perceived exertion and peak and cumulative low back extensor moment, likely due to the strong influence of task time duration on RPE. However, results from the current study indicate a weak relationship between perceived exertion and peak low back flexion angle and extensor moment within a PSW population, suggesting that short instances of moderate peak loading are not associated with RPE.

5.7. Implications Towards Workload Management as an Ergonomic Intervention

Through the characterization of a wide range of PSW work tasks and the quantification of the associated biomechanical exposures, several trends were identified. We know the injury mechanisms are commonly associated with different loading patterns. These data demonstrate that patient care tasks expose PSWs to long and extended durations of low to moderate loads in addition to increasingly flexed postures. When investigating risk, it might be important to consider these tasks from a cumulative load perspective. In contrast, patient transfer tasks imposes short durations of high peak loading suggesting that such tasks might be ideally considered from the perspective of acute loading. Given this understanding, it is logical to speculate that the risk of suffering an overexertion injury when performing a short duration, high force transfer task, could be increased if performed after extended exposure to tasks like bathing, dressing, undressing, etc. where the accumulated load may have further reduced the tolerance of tissues to withstand peak loading. This speculation provides an ideal opportunity for future research to better understand when PSWs most frequently report injuries, relative to the time-series loading exposures that they experience.

More specifically, these results inform what task characteristics could be tracked in order to have a pilot workload management methodology as we gain more clarity regarding the injury pathways that are associated with short duration high-dose tasks versus long duration low-dose tasks. Tasks such as patient transfers and repositioning tasks could be tracked using a frequency count of the number of transfers, while including patient weight as an additional surrogate measure to better understand the high-dose exposures being placed on the PSW. Specifically, aspects that strongly influence peak loading during these tasks such as patient weight, as mentioned previously, or patient mobility levels should be tracked as these strongly influence the physical demands of these tasks (Ho et al., 2023). Tasks such as bathing or dressing may be better tracked through aspects such as time duration, which better reflects the low loads that are being placed upon PSWs. Given the moderate relationship between RPE and cumulative extensor moment, RPE could also be collected to augment time tracking. As such, the tracking of these work metrics could allow for better planning and management when it comes to scheduling the PSWs to provide care for specific patients and the distribution of tasks that PSWs conduct per shift or per work week.

5.8. Limitations

While best efforts were taken to characterize biomechanical exposures during the performance of common and physically demanding PSW task, several limitations should inform the interpretation of the findings. As stated previously, due to issues with marker occlusion, the hands for some trials were missing and as a result, the kinematics of the hands were lost. To adjust for this, the mass of forearm was increased to reflect both the mass of the forearm and hand, and the COM location was adjusted further along the long axis of the forearm. It is expected that there would be minor differences in moments calculated as a result of this due to not having the exact location and position of the hands. As such, there may be differences in moment arm length (between the applied hand forces and the low back) if hand forces were to be applied at the center of the palm such as when the hands were tracked properly, versus if hand forces had to be applied to the distal forearm for instances where the hands were not tracked. To account for this issue, hand forces were applied consistently at the wrist joint center for all tasks. Therefore, for all tasks, there is likely to be an underestimation in the low back exposure metrics. However, it is expected that the difference would be small as the distance between the centre of the palm and the wrist joint center only spans approximately a few centimeters.

Force matching was used to estimate hand forces to apply to the Visual3D model. It is important to note that this methodology relies on the ability of the participant to replicate the force that they used to complete actions and subjective error is present. As well, due to restrictions with collection time, only a single measurement was taken, which can lead to error in the event that the effort did not represent the true effort.

Within this study, exposure metrics were calculated within the flexion-extension plane. However, it is noted well within research that asymmetrical loading such as lateral bend or twist moments is an important risk factor in work-related MSD development as well. With the data collected within the study, it is however, possible to calculate these metrics as well for examination.

Lastly, due to a smaller sample size, the regression analyses conducted in this study resulted in low R^2 estimates. As well, the low back exposure metric data obtained was skewed due to some participants due to demographic characteristics that are not representative of the PSW population. However, due to the small sample size, all participants were included in the analyses. With an increase in sample size, it is expected that there may be slight differences to the results produced, however, due to the strong correlations found between RPE and moment values, it is anticipated that these fit of the regression models will improve.

6.0. Conclusion

The characterization of low back biomechanical exposures for a range of PSW work tasks allows for better understanding of the potential injury pathways that might underpin the development of MSDs among PSWs. Specifically, it was found that PSW work tasks tend to cluster into two groups based on exposure profiles, where one group of tasks may expose PSWs to exposures that could be best considered through the paradigm of cumulative load theory and the other group exposes PSWs to acute doses of high magnitude loading. Patient handling tasks, including transfers and repositioning tasks, exposed PSWs to high loads for short time durations, and therefore, possess exposure patterns that better align with an acute trauma injury pathway. In contrast, patient care tasks such as bathing, dressing/undressing, and compression stocking application exposed PSWs to lower, but sustained and/or repetitive loads, and possess exposure patterns better aligned with a cumulative load theory. This study also identified a moderate association between RPE scores and cumulative low back extensor moment. Future research can explore if RPE is a suitable easy-to-use surrogate to monitor exposures related to a cumulative trauma injury pathway in order to inform work-rest strategies.

In the future, the increase in knowledge regarding PSW work tasks can inform the development of more targeted ergonomic interventions to protect the PSW worker population and to mitigate and decrease injury risk. This study provides evidence that it may be feasible to track cumulative loading through the reporting of task specific RPE scores, however, more research is needed to evaluate the use of RPE during real PSW work. As well, consideration of what task characteristics are best to track to quantify peak loads for tasks that follow an acute trauma injury mechanism is necessary to support a more robust method for workload management in PSW work.

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Appendices

Appendix A. Get Active Questionnaire

CSEP | SCPE
THE GOLD STANDARD IN EXERCISE SCIENCE AND PERSONAL TRAINING

Get Active Questionnaire

CANADIAN SOCIETY FOR EXERCISE PHYSIOLOGY –
PHYSICAL ACTIVITY TRAINING FOR HEALTH (CSEP-PATH®)

Physical activity improves your physical and mental health. Even small amounts of physical activity are good, and more is better.

For almost everyone, the benefits of physical activity far outweigh any risks. For some individuals, specific advice from a Qualified Exercise Professional (QEP – has post-secondary education in exercise sciences and an advanced certification in the area – see csep.ca/certifications) or health care provider is advisable. **This questionnaire is intended for all ages – to help move you along the path to becoming more physically active.**

☐ I am completing this questionnaire for myself.

☐ I am completing this questionnaire for my child/dependent as parent/guardian.

PREPARE TO BECOME MORE ACTIVE

The following questions will help to ensure that you have a safe physical activity experience. Please answer **YES** or **NO** to each question before you become more physically active. If you are unsure about any question, answer **YES**.

YES	NO	
		1 Have you experienced **ANY** of the following (A to F) **within the past six months**?
○	○	**A** A diagnosis of/treatment for heart disease or stroke, or pain/discomfort/pressure in your chest during activities of daily living or during physical activity?
○	○	**B** A diagnosis of/treatment for high blood pressure (BP), or a resting BP of 160/90 mmHg or higher?
○	○	**C** Dizziness or lightheadedness during physical activity?
○	○	**D** Shortness of breath at rest?
○	○	**E** Loss of consciousness/fainting for any reason?
○	○	**F** Concussion?
○	○	**2** Do you currently have pain or swelling in any part of your body (such as from an injury, acute flare-up of arthritis, or back pain) that affects your ability to be physically active?
○	○	**3** Has a health care provider told you that you should avoid or modify certain types of physical activity?
○	○	**4** Do you have any other medical or physical condition (such as diabetes, cancer, osteoporosis, asthma, spinal cord injury) that may affect your ability to be physically active?

NO to all questions: go to Page 2 – ASSESS YOUR CURRENT PHYSICAL ACTIVITY

YES to any question: go to Reference Document – ADVICE ON WHAT TO DO IF YOU HAVE A YES RESPONSE

Get Active Questionnaire

ASSESS YOUR CURRENT PHYSICAL ACTIVITY

Answer the following questions to assess how active you are now.

1 During a typical week, on how many days do you do moderate- to vigorous-intensity aerobic physical activity (such as brisk walking, cycling or jogging)?		DAYS/ WEEK
2 On days that you do at least moderate-intensity aerobic physical activity (e.g., brisk walking), for how many minutes do you do this activity?		MINUTES/ DAY
For adults, please multiply your average number of days/week by the average number of minutes/day:		MINUTES/ WEEK

Canadian 24-Hour Movement Guidelines recommend that adults accumulate at least 150 minutes of moderate- to vigorous-intensity physical activity per week. For children and youth, at least 60 minutes daily is recommended. Strengthening muscles and bones at least two times per week for adults, and three times per week for children and youth, is also recommended (see csep.ca/guidelines).

GENERAL ADVICE FOR BECOMING MORE ACTIVE

Increase your physical activity gradually so that you have a positive experience. Build physical activities that you enjoy into your day (e.g., take a walk with a friend, ride your bike to school or work) and reduce your sedentary behaviour (e.g., prolonged sitting).

If you want to do **vigorous-intensity physical activity** (i.e., physical activity at an intensity that makes it hard to carry on a conversation), and you do not meet minimum physical activity recommendations noted above, consult a Qualified Exercise Professional (QEP) beforehand. This can help ensure that your physical activity is safe and suitable for your circumstances.

Physical activity is also an important part of a healthy pregnancy.

Delay becoming more active if you are not feeling well because of a temporary illness.

DECLARATION

To the best of my knowledge, all of the information I have supplied on this questionnaire is correct.
If my health changes, I will complete this questionnaire again.

I answered NO to all questions on Page 1

Sign and date the Declaration below

I answered YES to any question on Page 1

Check the box below that applies to you:

- ☐ I have consulted a health care provider or Qualified Exercise Professional (QEP) who has recommended that I become more physically active.
- ☐ I am comfortable with becoming more physically active on my own without consulting a health care provider or QEP.

Name (+ Name of Parent/Guardian if applicable) [Please print] | Signature (or Signature of Parent/Guardian if applicable) | Date of Birth

Date | Email (optional) | Telephone (optional)

With planning and support you can enjoy the benefits of becoming more physically active. A QEP can help.

☐ Check this box if you would like to consult a QEP about becoming more physically active.
(This completed questionnaire will help the QEP get to know you and understand your needs.)

Appendix B. Nordic Musculoskeletal Questionnaire

How to answer the questionnaire:

Picture: In this picture you can see the approximate position of the parts of the body referred to in the table. Limits are not sharply defined, and certain parts overlap. You should decide for yourself in which part you have or have had your trouble (if any).

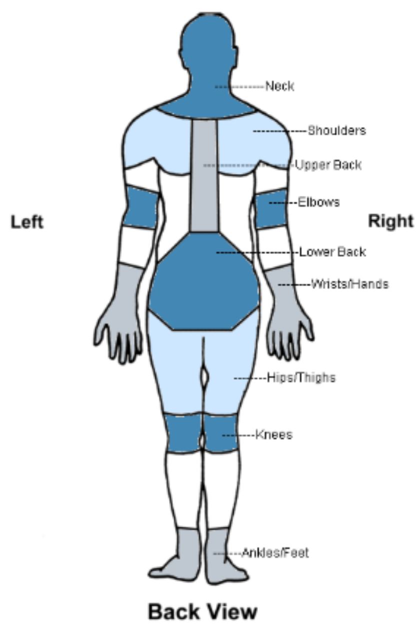


Table: Please answer by putting an "X" in the appropriate box - one "X" for each question. You may be in doubt as to how to answer, but please do your best anyway. Note that column 1 of the questionnaire is to be answered even if you have never had trouble in any part of your body; columns 2 and 3 are to be answered if you answered yes in column 1.

To be answered by everyone	**To be answered by those who have had trouble**	
Have you at any time during **the last 12 months** had trouble (ache, pain, discomfort, numbness) in:	Have you at any time during the **last 12 months been prevented from doing your normal work** (at home or away from home) because of the trouble?	Have you had trouble at any time during **the last 7 days?**
Neck ☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
Shoulders ☐ No ☐ Yes, right shoulder ☐ Yes, left shoulder ☐ Yes, both shoulders	☐ No ☐ Yes	☐ No ☐ Yes
Elbows ☐ No ☐ Yes, right elbow ☐ Yes, left elbow ☐ Yes, both elbows	☐ No ☐ Yes	☐ No ☐ Yes
Wrists/Hands ☐ No ☐ Yes, right wrist/hand ☐ Yes, left wrist/hand ☐ Yes, both wrists/hands	☐ No ☐ Yes	☐ No ☐ Yes
Upper Back ☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
Lower Back (small of back) ☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
One or Both Hips/Thighs ☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
One or Both Knees ☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
One or Both Ankles/Feet ☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes

Appendix C. Demographics Form

Date: ____/____/_______ ID Code: __________

dd mm yyyy

Participant Demographics Form

Demographics

Age: ________

Sex assigned at birth: ___________ Prefer not to answer

Gender: ________ Prefer not to answer

Height: _____ft/inch or cm

Weight: _____ kg or lbs

Handedness: Right-handed Left-handed

Footedness: Right-footed Left-footed

Information Regarding Your Occupation

What is your occupation/job?: ______________________________________

Years of experience: ______________

On average:

How many patients do you work with per day?_________; per week?________

How many hours do you work per day?_________; per week?_____________

For each of the following tasks, how many times do you do this per work day and per week?

1. Transfer patient from bed to wheelchair

   Per day: _________ Per week:___________

2. Transfer patient from wheelchair to bed

   Per day: _________ Per week:___________

3. Transfer patient from wheelchair to commode

Date: ____/____/_______

dd mm yyyy

ID Code: __________

Per day: _________ Per week:___________

4. Transfer patient from commode to wheelchair

Per day: _________ Per week:___________

5. Transfer patient from commode to bathtub

Per day: _________ Per week:___________

6. Transfer patient from bathtub to commode

Per day: _________ Per week:___________

7. Help bathe a patient

Per day: _________ Per week:___________

8. Help dress/undress a patient

Per day: _________ Per week:___________

9. Help patient put on compression stockings

Per day: _________ Per week:___________

10. Shift a patient up a bed

Per day: _________ Per week:___________

11. Push patient in a wheelchair around their home

Per day: _________ Per week:___________

Appendix D. Patient Profile

Patient Identification		
Name	Hailey Nestor	
Sex	Female	
Age	68	
Height	5’10	
Weight	190 lbs	
Patient Diagnosis (Conditions/Diseases)		
Diabetes	Patient suffers from peripheral edema in legs (swelling in lower limbs), therefore patient is required to wear compression socks and will require assistance to don/doff socks	
Arthritis	Patient suffers from moderate to severe arthritis in joints in lower limbs	
Patient Cognitive Review		
	Perception and communication	Patient has no severe deficits to vision. Patient can clearly communicate (hear and talk)
	Cognition and mood	No deficits
Patient Functional Review		
Mobility	Patient has moderate to severe deficits in lower limbs and slight deficit in upper limbs. Limited lower body mobility: Limited range of motion in back, knees and ankles. Decrease in active mobility of lower limbs. Decrease in strength in lower limbs. Patient has some paralysis in lower limbs that decreases patient’s ability to actively move their lower limbs, therefore patient has limited ability to walk and stand. Moderate mobility of upper body: Moderate range of motion in shoulders, elbows and neck. Slight decrease in active mobility of upper limbs. Slight decrease in strength in upper limbs.	
	Gait and speed	Patient able to walk with support (i.e., from PSW) for very short distances, must be monitored when walking, able to walk slowly.
	Weightbearing and standing	Patient can stand for short periods of time only with support (i.e., from PSW, while holding on to grab bars)
	Balance	Patient able to balance on two feet during standing with support (i.e., from PSW, from grab bars).
	Fall risk	Moderate fall risk. Patient must have support (i.e., from PSW, holding onto grab bars) when standing and/or walking. Must be monitored.
	Mobility aids	Patient uses manual wheelchair consistently around house.
	Footcare/footwear	Patient requires assistance to wear/take off compression stockings. Patient requires footcare, to be done by PSW as patient cannot reach legs/feet.
Activities of Daily Living		
	Bathing	**Assistive Level Required:** Patient requires assistance. Patient able to assist with cleaning upper body, but requires PSW to wash hair, back, perineal areas, legs and feet. For perineal care, patient is able to stand up from bathtub chair and stand for short period of time. Bathtub walls have grab bars that patient can hold onto while standing. PSW to assist patient to stand up/sit down from and to bathtub chair. **Assistive equipment:** bathtub chair (extended), grab bars on bathtub walls
	Dressing	**Assistive Level Required:** Patient requires assistance. Patient able to assist with dressing upper body, but requires PSW to dress lower body (i.e., undergarments, pants, compression socks). For pants, patient is able to stand for short period of time while holding onto wall grab bars. PSW to assist patient to stand up/sit down. **Assistive equipment:** grab bars on bathroom walls
	Transfers	**Assistive Level Required:** Patient requires assistance. Patient able to stand up or sit down with assistance from the PSW. Patient can walk a bit with support from PSW during the transfer (i.e., during stand and pivot transfers). For transfers from wheelchair to commode, wheelchair cannot fit into bathroom, so PSW will need to support patient to stand from wheelchair and to slowly walk short distance to commode. **Assistive equipment:** wheelchair, transfer belt (if deemed necessary from PSW)
Patient Goals		
	To use upper limbs as much as possible (i.e., during bathing, patient will clean upper body by themselves, will assist to put shirt on, etc.).	
	To assist as much as they can for tasks that require lower body mobilities (i.e., patient will try to shuffle close to edge during transfers, will stand supported for short periods of time with support for dressing tasks or to complete transfers).	
PSW Tasks		
	PSW to assist patient with ambulation as appropriate and to prevents/reduce risk of falls.	
	PSW to assist patient with personal hygiene (bed bath, shower, tub), especially with lower limb and perineal care. PSW to assist with putting on/taking off compression stockings.	

Appendix E. Task Descriptions

Task	Description
Block 1: Bedroom Tasks	
Transfer patient from bed to wheelchair	Starting set-up: Bed located in the corner of the simulated room and has top part folded down. Wheelchair is placed close to the bed. 1. PSW can adjust the wheelchair position. PSW can adjust the bed height. 2. PSW to assist patient to sit-up right in bed. 3. PSW assists the patient to bring their legs onto the ground, pivoting the patient. 4. PSW assists patient to stand up and pivots so that the patients rear is facing entrance of wheelchair. 5. PSW supports the patient as they sit down in the wheelchair.
Transfer patient from wheelchair to bed	Starting set-up: Bed located in the corner of the simulated room and has top part folded down. Wheelchair is placed close to the bed. 1. PSW can adjust the wheelchair position. PSW can adjust the bed height. 2. PSW to assist patient to stand up from the wheelchair and pivots so that the patients rear is facing the bed. 3. PSW assists the patient to sit down and then lefts their legs onto the bed while pivoting them. 4. PSW to assist the patient to lay down flat in supine position.
Shift patient up the bed	Starting set-up: Bed located in the corner of the simulated room. Patient is laying down in bed with the top off the bed down. The patient actor will lie with their head 35cm below the top of the mattress. 1. PSW to drop the rail of the bed. 2. PSW then to roll patient away from them to put the slider sheet underneath the patient. 3. PSW then roll patient towards themselves to get the slider sheet completely underneath patient. 4. PSW will then place the patient's legs in a bent position and tell patient to cross their arms. 5. PSW will grab onto the slider sheet and pull the patient to the head of the bed (as marked by tape that is 35cm below the top of the mattress).
Apply compression stockings on patient in bed	Starting set-up: Bed located in the corner of the simulated room. Patient is laying down in bed with the top off the bed upright. 1. PSW to roll up patient's pants. 2. PSW to start with one foot and applies a compression stocking, making sure that they are fully on. 3. PSW to apply compression stocking to the other leg.
Block 2: Bathroom Tasks (without bathtub)	
Transfer patient from wheelchair to commode	Starting set-up: Commode located in simulated bathroom, between the bathtub and sink. Patient is sat on the commode. Wheelchair is placed at the entrance of the room and is unable to go into the bathroom. 1. PSW assists patient to stand up from the wheelchair. 2. PSW supports patient as they walk the patient towards the commode. 3. PSW to help patient to turn so that their rear is facing the commode. 4. PSW assists patient to sit down on the commode.
Transfer patient from commode to wheelchair	Starting set-up: Commode located in simulated bathroom, between the bathtub and sink. Patient is sat on the commode. Wheelchair is placed at the entrance of the room and is unable to go into the bathroom. 1. PSW assists patient to stand up from the commode.

	2. PSW supports patient as they walk the patient towards the wheelchair. 3. PSW to help patient to turn so that their rear is facing the wheelchair. 4. PSW assists patient to sit down on the wheelchair.
Apply compression stockings on patient sat on the commode	Starting set-up: Commode located in simulated bathroom, between the bathtub and sink. Patient is sat on the commode. 1. PSW to roll up patient's pants. 2. PSW to start with one foot and applies a compression stocking, making sure that they are fully on. 3. PSW to apply compression stocking to the other leg.
Dress the patient	Starting set-up: Patient is sitting in commode. Patient will be wearing long-sleeve and long-legged clothing that is tight to the body (to allow for easier application of the additional clothing. Simulated grab bars will be on the wall across from the commode. 1. PSW will assist patient in putting on a shirt. 2. PSW will help patient to put on a pair of pants. PSW may ask the patient to stand up and support themselves on the commode while pulling the pants up. PSWs may assist the patient to stand up and walk to the grab bars, then pull pants up while patient supports themselves. PSWs may have patient shift their weight side to side while sat on the commode while PSW pull pants up.
Undress the patient	Starting set-up: Patient is sitting in commode. Patient will be wearing long-sleeve and long-legged clothing that is tight to the body (to allow for easier application of the additional clothing. Simulated grab bars will be on the wall across from the commode. 1. PSW will assist patient in in taking shirt off. 2. PSW will help patient to take off pants. PSW may ask the patient to stand up and support themselves on the commode while pulling the pants off. PSWs may assist the patient to stand up and walk to the grab bars, then pull pants off while patient supports themselves. PSWs may have patient shift their weight side to side while sat on the commode while PSW pull pants off.
Block 3: Bathroom Tasks (with bathtub)	
Transfer patient from commode to bathtub	Starting set-up: Within the simulated bathroom. Shower chair is placed in the bathtub. 1. PSW assists patient to stand up from the commode. 2. PSW supports patient and pivots them towards the bathtub so that their rear is facing the edge of the shower chair. 3. PSW assists patient to sit down on the shower chair. 4. PSW to lift patient's legs into the bathtub. 5. PSW to help shift the patient into the center of the shower chair.
Transfer patient from bathtub to commode	Starting set-up: Within the simulated bathroom. Shower chair is placed in the bathtub. 1. PSW to help shift patient near the edge of the shower chair. 2. PSW to lift patient's legs out of the bathtub. 3. PSW assists patient to stand up from the shower chair. 4. PSW supports patient and pivots them towards the commode so that their rear is facing the seat. 5. PSW assists patient to sit down on the commode.
Perform simulated bathing task	Starting set-up: Patient is sitting on the shower chair in the bathtub. A simulated shower head is placed on a rack at the front of the bathtub and a product bottle and washrag is placed on the bathtub ledge. Simulated grab bars are on the wall near the top of the bathtub. 1. PSW to turn on the faucet. 2. PSW to simulate washing patient's hair. This includes grabbing products from the bathtub ledge, rubbing the patient's head and using the showerhead to pretend to rinse.

	3. PSW will use a washrag and simulate washing the patient's entire body (arms, body, perineal areas, legs, feet). When washing, PSW may choose to help patient to stand up from the shower chair to wash perineal areas. 4. PSW will rinse the patient's entire body. 5. PSW will return shower head and turn off the faucet.

Appendix F. Post-Collection Survey

Exit Questionnaire

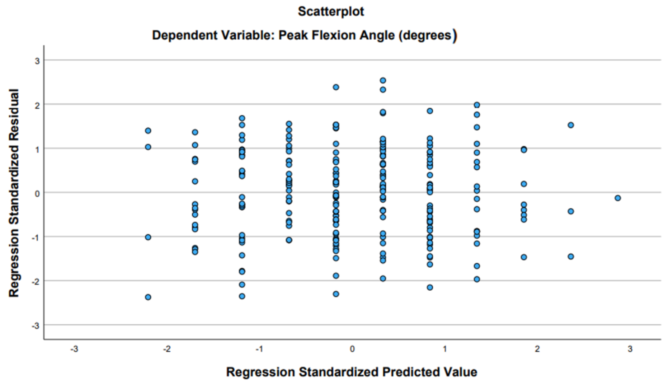
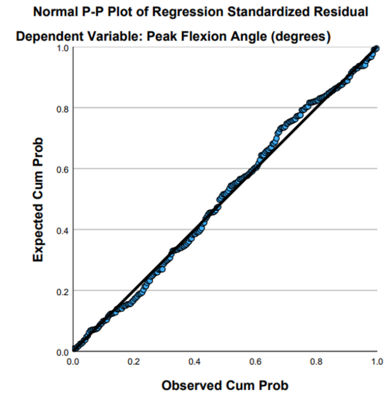
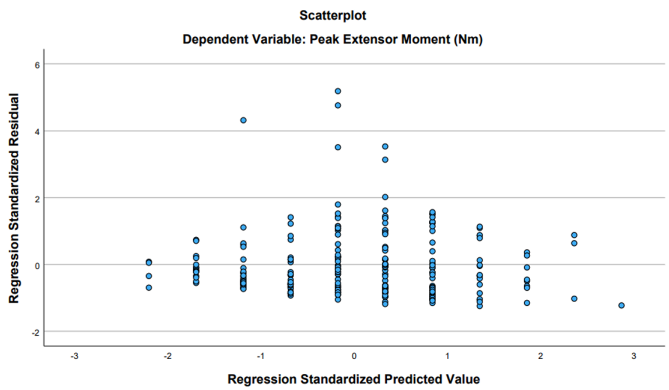
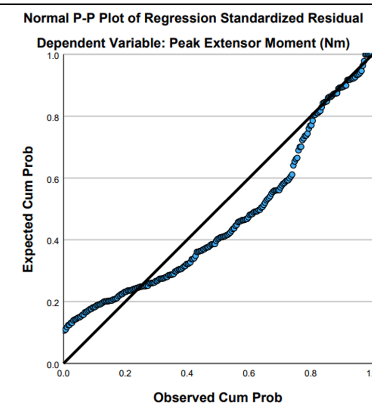
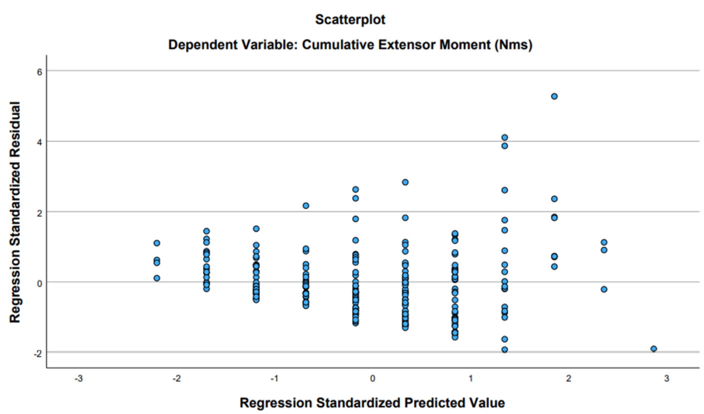
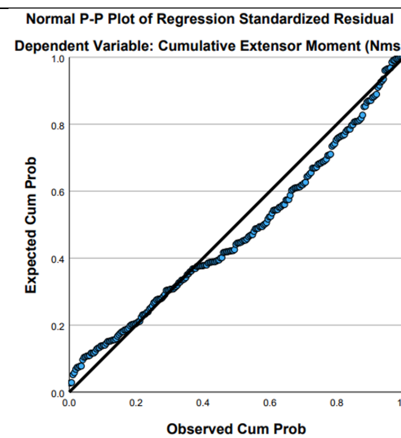
Participant ID:______________

From a scale from 1-10, how realistic were the tasks you completed during the collection compared to how you complete these tasks in your actual work?

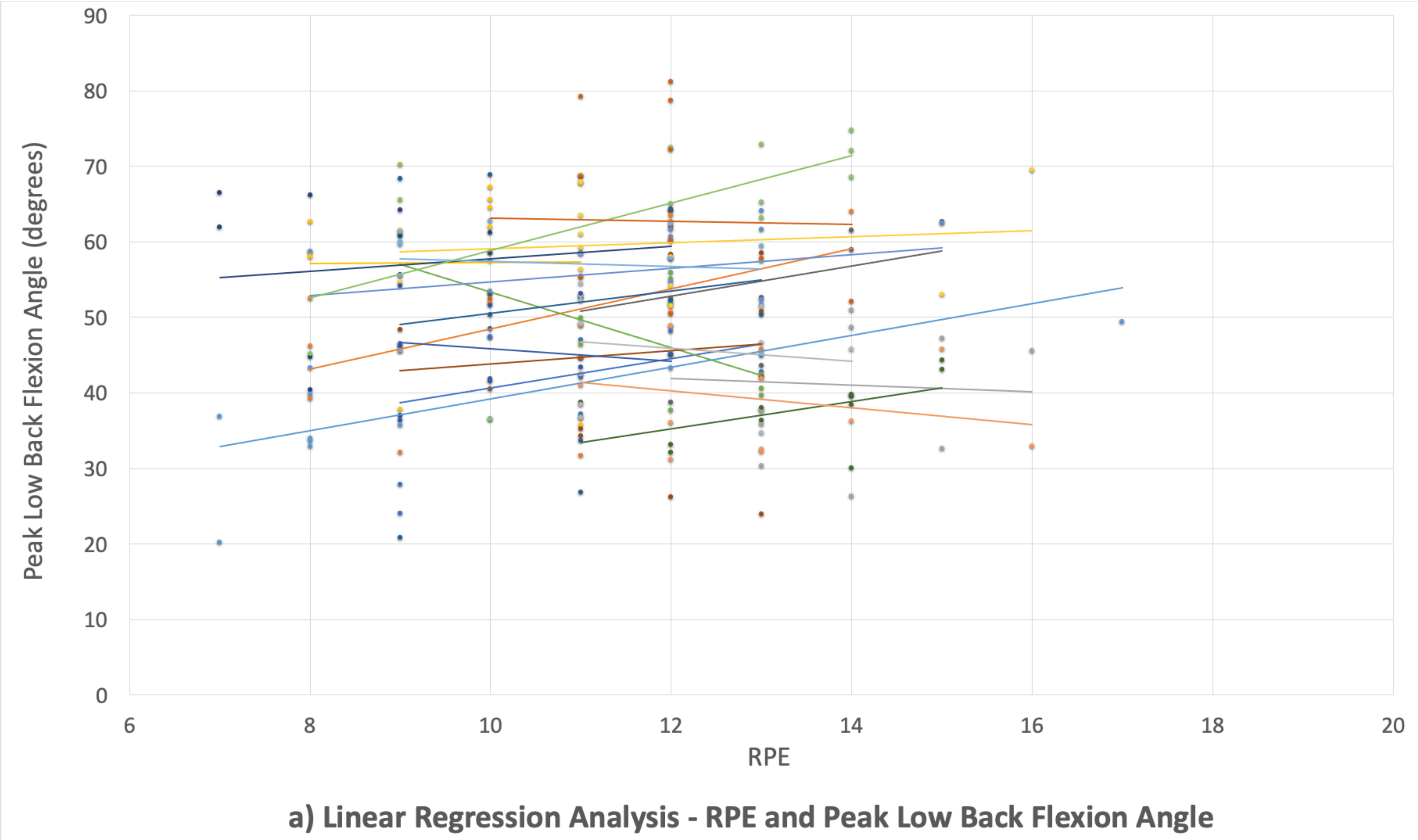
1	2	3	4	5	6	7	8	9	10
Not realistic at all									Exactly the same as actual work

____

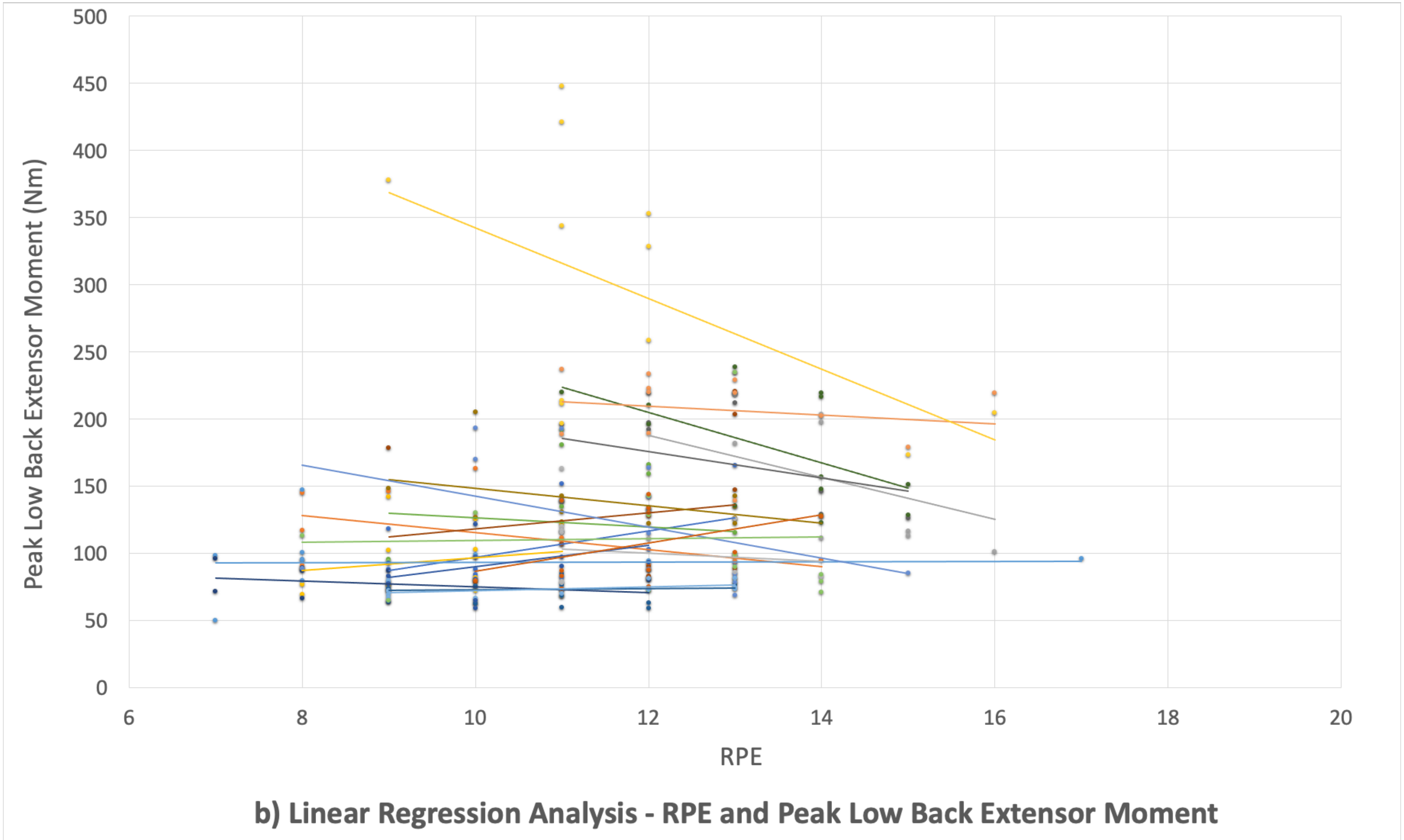
Appendix G. Results from assumption testing for regression analyses.

Independent Variable	Dependent Variable	Scatterplots – Predicted Values - Residuals	P-P Plots	Interpretation
Post-task RPE	Peak Flexion Angle (˚)			Assumptions of homoscedasticity and normality are met.
Post-task RPE	Peak Extensor Moment (Nm)			P-P plot indicates relatively normally distributed data. Scatterplots indicate there is some skewness in the data, but no clear violation of homoscedasticity.
Post-task RPE	Cumulative Extensor Moment (Nm*s)			P-P plot indicates relatively normally distributed data. Scatterplots indicate there is some skewness in the data, but no clear violation of homoscedasticity.

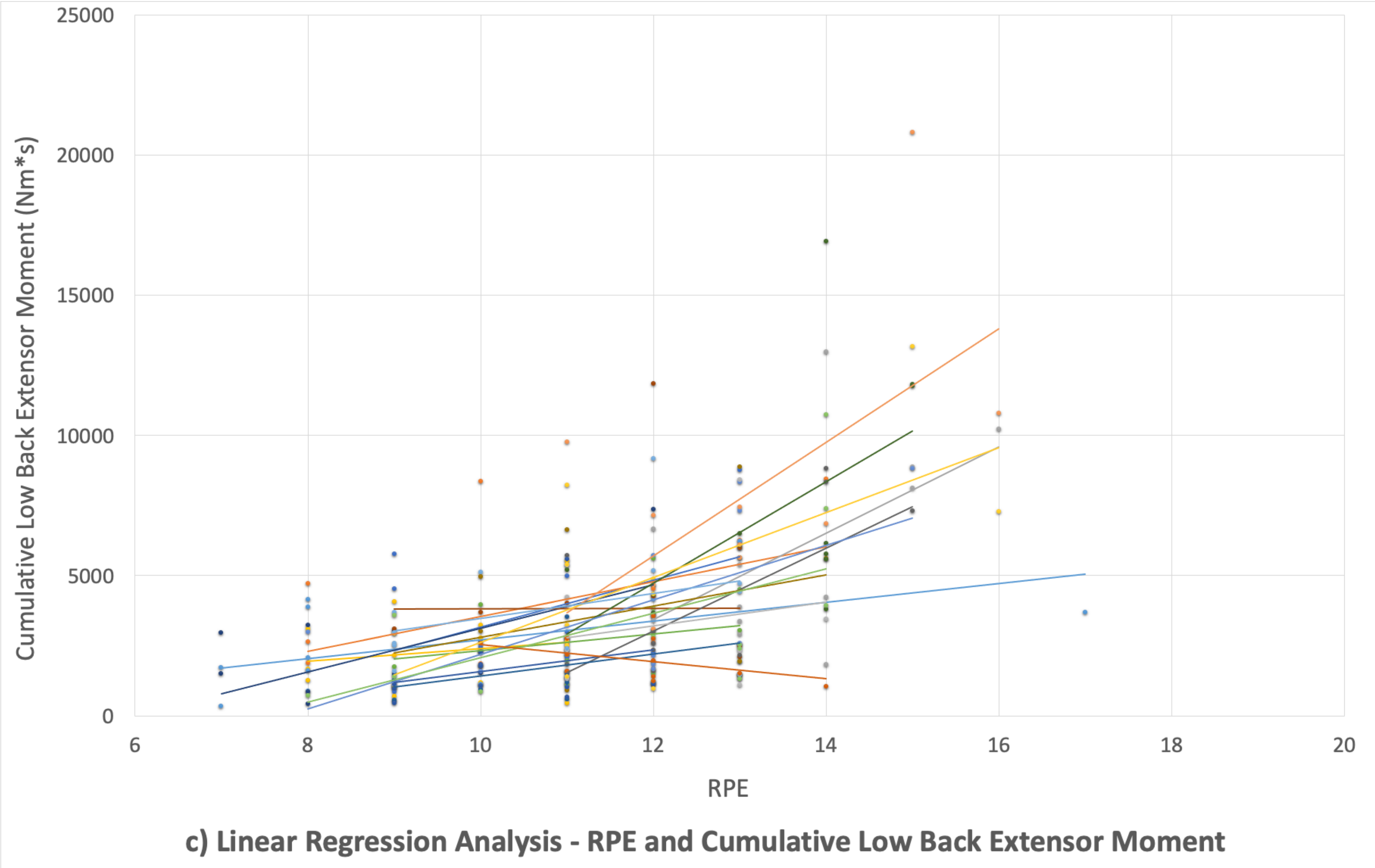
Appendix H. Participant-specific linear regression lines for each low back exposure metric.



Note. Each colour (data points and regression line) on the graph represents a different participant.



Note. Each colour (data points and regression line) on the graph represents a different participant.



Note. Each colour (data points and regression line) on the graph represents a different participant.