Defining Normative Upper Limb Kinematics during Functional Capacity Evaluation (FCE) Task Performance

by

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Authors 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 reviewers.

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Abstract

The Functional Capacity Evaluation (FCE) is an evaluation tool used in the return to work process to guide treatment and decision making. An FCE involves testing the functional abilities of an individual to determine their return to work readiness. A patient's maximum capacity and functional abilities are determined either through subjective measures of exertion or visual observations of mechanics. Even though the observational method is more objective and reliable, descriptions of kinematics to guide evaluations are limited. Therefore, the main purpose of this investigation is to provide a comprehensive description of the kinematics of the upper extremity of a healthy population during upper extremity focused FCE tasks.

Upper limb and torso kinematic data were collected on 30 young, healthy participants as they performed five FCE tasks (repetitive reaching, fingertip dexterity, hand and forearm dexterity, waist to overhead lift, and overhead work). Kinematic profiles were created for all clinically relevant angles of the torso, shoulder, elbow, and wrist. Segment velocities were also calculated for each task.

Sex did not influence kinematics or segment velocity, but intensity changes resulted in significant differences for both measures. For example, in the waist to overhead lift, maximum torso extension increased by 10.44° and minimum humeral flexion decreased by 11.35° and 12.07° for the right and left arm, respectively. During the overhead work task, mean torso extension increased by 6.90° and mean internal rotation of the right and left humerus increased by 13.58° and 14.26°, respectively. Segment velocities also increased by up to 50% during the waist to overhead lift and up to 82% in the overhead work task.

The results of this study indicate many of these tasks require large ranges of motion and high demand postures for the upper limb, specifically for the shoulder and wrist. The reaching and dexterity tasks often required up to 60° of arm elevation, while the overhead tasks required

arm elevation consistently greater than 90°. Additionally, for several tasks in this investigation, wrist extension and ulnar deviation angles remained around 20°, which is a large portion of the available range of motion of the wrist. Conversely, torso postures were almost always less than 30° away neutral and the elbow often remained within 60°-100° of flexion, the strongest elbow position, indicating the FCE tasks may not be as useful for evaluating these angles, but they should still closely monitored for potential compensations used by injured patients.

The typical torso and upper limb kinematic profiles provided in this investigation is largest dataset of its kind to date. Clinicians and scientists will find the profiles useful because they provide a baseline to which motion can be compared to in order to better evaluate FCE performance. These data also improve the identification of a safe maximum capacity for overhead lifting and prolong overhead work tasks, allowing evaluators to better understand each patient's abilities. This work supports the more ambitious future clinical goal of being able to identify people who are at risk of further injury or disability if returned to work too early.

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For my Dad,

To whom I owe it all

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Chapter 1: Introduction

Time loss injuries are a major burden on the working population and the health system, both financially and socially. In 2008, worker compensation boards across Canada spent $7.67 billion in direct benefit payments to workers with a time loss injury. When factoring in additional direct and indirect costs, it is estimated that the total cost of national lost time injuries is $19 billion annually (Gilks & Logan, 2010). While there has been a large focus on decreasing workplace injuries, and some success in decreasing incidence rates in Canada (Gilks & Logan, 2010), time loss injuries are still common for many workers and companies. These injuries need to be addressed in a safe and effective manner to decrease economic and personal costs.

Historically, the return to work process is guided by pain management. However, by shifting the focus to the functional abilities of the patients, return to work can occur sooner, and there is less lost time due to the pain or injury later (Saunders, 1995; Oesch, Kool, Bachmann, & Devereux, 2006). To accomplish function-centered rehabilitation, evaluators often use a version of a Functional Capacity Evaluation (FCE) for guidance.

1.1 Functional Capacity Evaluation Overview

The purpose of the return to work process is to match the worker's post injury physical abilities to their job demands to ensure that they can perform work tasks free of impairments and with a decreased risk of re-injury. Strength testing has similarly been used for worker selection and in work placement programs with the goal to ensure that only people with sufficient strength to perform a job safely will be assigned to that job (Chaffin, Andersson, & Martin, 2006). This idea has been supported by research involving the application of strength tests to those with lower back pain; subjects performing jobs that required strength greater than their isometric test result were more likely to have pain (Chaffin & Park, 1973; Chaffin, Herrin, & Keyserling, 1978; Keyserling, Herrin, & Chaffin, 1980). By testing a worker's strength, one can determine if they can physically perform the duties of a particular job based on its strength requirements. The FCE can be used in the same manner for both post offer-pre employment and return to work subjects, but has the added benefit of the ability to evaluate both capacity and mechanics to determine abilities.

A complete FCE often includes several steps: typically an interview or questionnaire, a physical exam, physiological measures, and functional measures. The functional measures portion was the focus of this research. Application of this FCE portion in practice varies considerably depending on the FCE system and the patient's injury. For instance, the functional measures used to assess a lower limb injury typically differ from those used for an upper limb injury. Functional tests should also be influenced by the patient's occupation. The tests should clearly evaluate the patient's ability to perform the essential functions of their particular job; as an example, if the patient is an office worker, a crawling ambulation test would be of little utility. Nevertheless, tasks that are commonly used to assess the overall functional abilities include lifting, carrying, pushing/pulling, overhead work, forward bending, kneeling or crawling, squatting, reaching, walking or stair climbing (Reneman, et al., 2004).

The role of the evaluator in an FCE is to use the information collected in the evaluation to match the patient's ability to their job demands. An FCE evaluator is usually an occupational therapist, physiotherapist or kinesiologist (Strong, et al., 2002). Physicians, nurses or employees worker's compensation boards also administer the FCE, albeit less often (Strong, et al., 2002); thus there is a large range of skill level and background knowledge of evaluators. Maximum capacity scores as determined by the evaluator are ultimately used to decide if the patient is able to return to work, and can vary with this range of knowledge and experience.

There are two main assessment approaches used by evaluators during an FCE that differ in their test termination criteria. One approach, the psychophysical approach, uses the patient's subjective perception of their own maximum to end the test. The other method, the kinesiophysical approach, relies on the observation of mechanics to determine the patient's maximum. When mechanics are considered by the physician or therapist during a functional evaluation, the FCE becomes more objective and reliable (Isernhagen, 1995). However, the currently available criteria used for classifying mechanics during the FCE is limited.

1.2 Need for Normative Kinematic Data of FCE Task Performance

An essential aspect of the FCE process is the evaluator's ability to interpret the patient's performance. Interpretation of capacity outcomes is guided by normative capacity data or results from a job demands analysis but the interpretation of body mechanics and posture for many tasks lacks guidance.

Possessing normative typical upper extremity kinematic data from FCE tasks enhances understanding of movement during these tasks, making the kinematic components of FCE's easier to interpret and improving the consistency of the return to work evaluation process. These data provide a baseline for comparison for future analysis of injured populations, such as those with rotator cuff tear repairs or breast cancer survivors. By understanding healthy movement in these tasks and then identifying the differences seen in injured populations, evaluators can more easily and reliably recognize pathological or atypical motion. The identification of atypical motion can then be used to guide treatment or to determine how a job can be modified to decrease risk of re injury and return the worker to the job sooner.

Several aspects of performance must be considered by evaluators during FCE's: body mechanics, compensatory movements, changes in speed or control of movement, muscle tremor, facial expressions, and competitive test behaviors are prime examples (Chappell, Henry, McLean, Richardson, & Shivji, 2006). Thus, evaluators need to determine which specific performance attributes merit closest monitoring. Normative kinematic data can help evaluators direct their attention to those aspects of motion that typify healthy movement. In addition, the identification of normal movement compensations caused by varying the level of intensity in work capacity tasks also allows for a more objective return to work decision. An assumption of the kinesiophysical approach is that a patient's mechanics change as maximum capacity is reached, so this dataset provides descriptions of movement at varying levels of intensity (Isernhagen, 1992). Because obvious changes occur, the kinesiophysical approach of using observations to objectively determine maximum capacity is justified. For instance, wrist ulnar deviation, shoulder flexion, and torso flexion/extension all differed at varying levels of intensity in the waist to overhead lift, so evaluators can focus their attention to these aspects of motion to identify changes and determine abilities.

Some previous guidelines for observation of mechanics during FCEs have been described, but they have nearly exclusively been applied to floor to waist lifting tasks (Reneman, Fokkens, Dijkstra, Geertsen, & Groothoff, 2005; Smith, 1994). In addition, aspects of the established definitions are vague. For instance, Isernhagen, Hart, & Matheson (1999) suggest that observing muscle recruitment can aid in evaluating the effort of a lift. The Isernhagen criteria states that during a heavy lift the evaluator will observe "pronounced recruitment of accessory muscles and trunk and neck stabilizers" (Isernhagen, Hart, & Matheson, 1999, p. 148). This type of criteria is difficult to use as it is challenging to observe and distinguish individual muscle contributions, let alone estimate different levels of recruitment within them. Further, for non-lifting tasks, observation criteria directs evaluators to classify functional abilities of a patient based on their deviation from normal (Trippolini, et al., 2014a) but almost no description of normal movement is provided. Normal movement must first be clearly documented and understood before deviations caused by injury or work intensity can be identified.

1.3 Purpose

The purpose of this project is to investigate upper extremity kinematics of a young (18-35), healthy, control population during select tasks of a Functional Capacity Evaluation (FCE); this provides a comprehensive description of normative upper extremity movement strategies and also characterizes FCE task upper extremity movements at a higher resolution than previously accomplished.

Specifically, the purposes of this study were to:

1) Define the normative upper extremity kinematics of healthy participants during upper extremity focused FCE tasks including lifting, reaching and dexterity, and prolonged posture tasks.
    a. Calculate mean and peak joint angles for the wrist, elbow, shoulder, and torso during each task.
    b. Calculate mean and peak velocity of the hand, forearm, upper arm and torso during each task.
2) Determine if sex, load, or task duration affect kinematics in FCE tasks
3) Define how kinematics change as load and task duration increase to maximum capacity during the lifting and prolonged posture tasks.

1.4 Hypotheses

This investigation will quantify upper extremity kinematics during select tasks of Functional Capacity Evaluations. The specific hypotheses of this investigation are:

1) **Sex will influence kinematics outcome variables in all FCE tasks.**

   Men and women differed on several measures during a floor to waist lifting task in prior research (Lindbeck & Kjellberg, 2001), indicating that differences are likely present in other types of lifts as well. Sex also influences reaching to specific targets after eliminating stature effects (Chaffin, Faraway, Zhang, & Woolley, 2000). Moreover, Barnes, Van Steyn, & Fischer (2001) determined that females had significantly larger shoulder range of motion for all axes than males, which could also influence kinematics.

2) **Load magnitude and task duration will influence kinematics outcome variables during lifting and posture tasks. Kinematics will differ as a function of task capacity with largest differences from baseline occurring at maximal task capacity.**

   The kinesiophysical approach for assessing FCEs requires the evaluator to determine maximum capacity by observing adverse changes in motion. Using this approach, a patient's biomechanical maximal capacity is defined as the highest level of capacity performed with safe kinematics as determined by the evaluator (Smith, 1994). Previous research has investigated the ability to successfully distinguish between different intensities of floor to waist lifts and one kinematic analysis of submaximal and maximal overhead lifts found differences in several joint angles in the sagittal plane (Allen, James, & Snodgrass, 2012), indicating there is a transition of mechanics as intensity increases. Biomechanical indicators have also been reported to be used by evaluators when assessing static standing in an FCE (Nicholls, Gibson, McKenna, Gray, & Wielandt, 2011), suggesting biomechanical changes will occur in other types of prolonged posture tasks.

Chapter 2: Literature Review

This review of the literature provides definitions and background information for Functional Capacity Evaluations (FCE), an overview of the general process and a summary of major commercially available FCE systems. The reliability of the FCE is detailed and currently used observation criteria are explored. Current normative data for the FCE is reviewed and the need for normative kinematic data for FCE task performance discussed. Finally, movement differences between healthy and injured persons are presented to underscore the utility of normative kinematic data for identifying movement characteristics observationally during FCE.

2.1 Functional Capacity Evaluation

2.1.1 Definition and purpose of FCEs

Traditionally, return to work decisions have been based on a physician's subjective assessments from physical examinations and the patient's self-reported functional capacity (Mitchell, 2008). However, based on those assessments, it is unlikely that a physician would identify the true capacity of the patient or be able to accurately assess many important variables necessary for return to work, like strength, dexterity or endurance (Mitchell, 2008). As such, the need for an objective tool to measure work capacity and functional limitations of the patient led to the development of Functional Capacity Evaluations.

Functional capacity evaluations (FCEs) are objective, standardized batteries of physical performance and functional measures that are used to determine a person's ability to perform work related tasks (King, Tuckwell, & Barrett, 1998; Gross & Battié, 2003).

There are 3 specific purposes for FCE's, according to Matheson (1996):

1. To improve the likelihood that the injured worker will be safe in future work performance.

2. To identify functional limitations so they can be resolved or worked around through return to work modification.
3. To determine the presence and level of disability to aid in legal or insurance cases.

2.1.2 Approaches for an FCE assessment

There are two main approaches to the FCE:

1) The psychophysical approach (Snook & Irvine, 1969), which involves the patient determining the endpoint of the task based on their perception of their own maximum, or

2) The kinesiophysical approach (Isernhagen, 1992), which relies on the evaluator to determine maximum function based on observations of physical movements.

The psychophysical approach has been used to develop guidelines for safe maximum intensities for a normal, healthy working population, but within an FCE, the patient's subjective feeling of maximum determines the termination of functional tests. This approach represents a measure of what a patient will do, compared to what they can do (Snook & Irvine, 1969).

It is well known to physicians, therapists, and other evaluators that the perceptions of injured workers are not always accurate. In 1980, Waddell, McCulloch, Kummel & Venner investigated nonorganic physical signs of pain, such as tenderness, regional sensory changes and overreaction and found that they were commonly seen in patients involved in legal cases and compensation claims, as is often the case when an FCE is performed. Therefore, there it is difficult to determine if a patient's reaction to a task is genuine and if the performance is indicative of a true maximum when the patient controls endpoint determination. Thus, an evaluator would not get an objective picture of the patient's abilities using this approach.

In contrast to the psychophysical approach, the kinesiophysical approach focuses on observable functional abilities and limitations to make return to work decisions. While the psychophysical method is not sensitive to select movements associated with injury, like the effect of bending and twisting on low back injury (Snook, 1985), an evaluator using the kinesiophysical approach is able to observe these movements, match them to the diagnosed injury, and then alter treatment to effectively address poor technique and movement deficiencies (Johnson, 1995). Modifications can also be made to the patient's job to address high risk or injury aggravating movements observed in the evaluation so they can return to work as quickly as possible. Often even a minor modification based on information from an FCE can allow the worker to return to work both promptly and safely (Johnson, 1995).

2.1.3 FCE process and commercially available systems

The specific steps involved in a complete FCE vary depending on the evaluator, the system, and the patient, but the general process often includes several steps (Table 1).

Table 1: Components of a full FCE *(King, Tuckwell, & Barrett, 1998)***.**

Component	Description
Client questionnaire or interview	Information such as medical history, work history, current level of physical activity, level of functioning in daily living or work activities, and job satisfaction.
Physical Examination	Includes measuring heart rate and blood pressure and a musculoskeletal evaluation that can identify contraindications to testing or areas that need close monitoring during certain tests.
Physiological measures	For either muscle or cardiovascular endurance. These can be evaluated using duration of performance prior to fatigue or through measurement of heart rate during submaximal protocols that have pre-determined endpoints.
Functional performance	Includes the functional tests of the FCE that are the focus of this investigation. These include tasks such as lifting, reaching, postural tolerance and ambulation that are included to replicate common work tasks.
Job Demands Comparison	Final step of the FCE. This involves the comparison of results to the patient's job demands to determine if they are able to return to their daily duties without fear and with decreased likelihood of re-injury.

There are several different commercial FCE systems available but they all share the same goal: to objectively measure work related functional performance (King, Tuckwell, & Barrett, 1998). Nonetheless, there are several differences in the procedures and equipment between the commercially available FCE systems. Several systems sell specialized equipment and software, ranging from approximately $1,000 (WorkWell System) up to $100,000 (all modules of the ERGOS work simulator) (King, Tuckwell, & Barrett, 1998).

Systems like the ERGOS work simulator, the Baltimore Therapeutic Equipment (BTE) Work Simulator, or the ARCON system include evaluation tools with varying attachments that connect to software used to collect and report capacity information. Systems such as these have attachments like turning wheels or crank handle attachments, levers for pushing and pulling, an overhead reach attachments, and grip strength attachments that output variables like torque, work, and power (Bhambhani, Esmail, & Brintnell, 1994; Lomond & Cote, 2011b). This type of data is collected during the tasks and is used to predict functional ability based on the formulas and norms built into the software. However, how these tasks and results relate to each patient's work tasks is unclear. The construct validity of the BTE was only acceptable for light tasks and therefore judgement on a patient's abilities at any other intensity should be used with caution (Kennedy & Bhambhani, 1991).

Other FCE systems require less expensive and less cumbersome equipment such as push/pull, hand grip or pinch dynamometers, standardized dexterity tests, standard sized lifting containers and adjustable shelving units during evaluations. According to Soer et al. (2009), the WorkWell System (WWS), which the tasks in this investigation are based on, is one of the systems that does not rely on complicated tools. A benefit to using more basic equipment is not only seen in the cost, but also allows for tasks that are directly related to the work place. In addition, this system depends on the evaluator's observations to determine functional ability and predict how often the task can be performed during a work day (King, Tuckwell, & Barrett, 1998).

Procedures and protocols also vary across systems and can have an effect of final determination of functional ability. Lifting protocols are the most prevalent in the literature and are prime examples of the differences between systems. Two different protocols that are commonly used to evaluate lifting functional capacity are the PILE (Progressive Isoinetrial Lifting Evaluation) and EPIC Lifting Capacity (ELC) test (Jones & Kumar, 2003). The PILE test requires the participant to lift a weighted box four times in 20 seconds from the floor up to a table that is 75 cm high, regardless of the participant's stature. The weight of the box is increased after every set of 4 lifts. A psychophysical approach is often used with the PILE test, meaning the test is terminated when the subject feels fatigued (Mayer, et al., 1988). In the ELC the table height is dependent on the height of the patient, and the patient lifts the box from floor to low shelf or low shelf to high shelf either one or four times every 30 seconds, with the weight increasing after every set. The test can be terminated based on changes in posture and muscle recruitment or self-perception of maximum (Matheson L. , et al., 1995). The different lifting heights, different number of cycles, varying test durations, and different termination criteria in just these two tests clearly demonstrates the many potential different procedures and protocols between FCE systems. It is not always clear how choosing one over the other would affect return to work decisions.

Two other lifting procedures, the WWS and Ergo-Kit upper lifting tests, were compared and found that they were too different to be used interchangeably. The type of box and handles, heights of the shelves, weight increments, number of repetitions and sets, and test termination criteria were substantially different between the two protocols (IJmker, Gerrits, & Reneman, 2003). The only evidence in the literature to support the use of one system's protocol over the other is based on reliability studies. A comparison of 4 different systems determined that only the WWS had good reliability and predictive validity (Gouttebarge, Wind, Kuijer, & Frings-Dresen, 2004) and this will be discussed in more detail below.

Finally, it is suggested that the procedures of all FCE systems can be modified to each individual and their occupation to most efficiently evaluate functional capacity (Gouttebarge, Wind, Kuijer, Sluiter, & Frings-Dresen, 2010). For instance, Gross, Battié, & Asante (2007) found that the short form of the WWS FCE reduces assessment time without affecting the recovery and may be useful for fitness-for-work assessment. Specifically for upper extremity injuries, not all tasks in the WWS FCE are required and thus only select tasks will be tested in this investigation (Reneman, Soer, & Gerrits, 2005).

2.1.4 Reliability and Validity of the FCE

Several authors have established the reliability and construct validity of the tasks of the WWS FCE (Gross & Battié, 2003; Brouwer, et al., 2003; Hart, 1988; Reneman, Dijkstra, Westmaas, & Göeken, 2002; Reneman, Fokkens, Dijkstra, Geertsen, & Groothoff, 2005). Gross and Battié (2003) stated that the construct validity of the WWS FCE supports its use as a measure of function, while the inter-rater and intra-rater reliability of the static push/pull (Hart, 1988), lifting and carrying tasks (Reneman, Dijkstra, Westmaas, & Göeken, 2002), and prolonged posture (Reneman, Bults, Engbers, Mulders, & Göeken, 2001) tasks of the WWS FCE were studied individually and determined to be good. Following those investigations, the reliability of the entire WWS FCE protocol was studied and the test-retest reliability for both healthy adults and patients with chronic low back pain was determined to be acceptable (Brouwer, et al., 2003; Reneman, et al., 2004).

The reliability of a clinician's ability to classify level of effort through observation is an important aspect of FCEs. This ability has been mostly tested on clinician's rating of floor to waist lifting using observational criteria developed specifically for this task (Smith, 1994; Gross & Battié, 2002; Trippolini, et al., 2014a). The reliability of using observation to classify submaximal and maximal effects during the WWS FCE lifting and carrying tasks was high to excellent in many investigations (Gross & Battié, 2002; Reneman, Jaegers, Westmaas, & Goeken, 2002; Reneman, Fokkens, Dijkstra, Geertsen, & Groothoff, 2005). In contrast, the reliability for identifying effort in non-manual material's handling tasks was lower (Trippolini, et al., 2014a), possibly because the observation criteria for these tasks has not been investigated as expansively.

Successfully identifying varying effort levels in FCE tasks allows evaluators to not only identify maximum capacity level but also helps determine the sincerity of effort of the patient. If the patient does not give a maximum effort, the true capacity cannot be determined and the reliability of the test will be compromised. Nonorganic signs of pain (Waddell, McCulloch, Kummel, & Venner, 1980) can be used to determine sincerity, however it has been suggested that a trained observer can better distinguish effort by observing mechanics than using physiological signals (Hazard, Reeves, & Fenwick, 1992; Reneman, Fokkens, Dijkstra, Geertsen, & Groothoff, 2005). For instance, one investigation examined kinematics during real versus feigned efforts in lifting tasks and found significant differences in mean velocity, peak velocity, and terminal acceleration (Marmer, Velasquez, & Cifu, 2002). Feigned effort movements were slower and more deliberate, which is thought to exhibit one's inability to perform the activity. Therefore, using observation to classify effort level has been proven to be valid and reliable and also offers unique information about patient effort level that is not provided in any other approach.

There is a caveat to the reliability of the FCE: differing experience and knowledge of mechanics will affect the quality of the FCE results. A thorough understanding of anatomy and mechanics was seen as essential to occupational therapists that regularly perform FCEs (James, Mackenzie, & Higginbotham, 2007). However, because evaluators from several health care professions currently administer FCEs, ranging from physiotherapists and occupational therapists to athletics trainers, psychologists, and physical or occupational therapist assistants, the skill level and knowledge can differ from any one evaluator to the next (King, Tuckwell, & Barrett, 1998). To address this difference in experience, evaluator training and guidance becomes an important element of FCEs (King, Tuckwell, & Barrett, 1998; Mitchell, 2008). To ensure good reliability and validity of an FCE, sufficient descriptions of safe mechanics from healthy populations is necessary.

2.1.5 Effectiveness and Predictive Ability of the FCE

When function centered treatment is used to rehabilitate injured workers, the amount of lost time decreases and number of working days increases. When comparing function centered treatment and pain centered treatment for workers with low back pain, more workers in the functioned centered treatment returned to work, either with or without a modification, and had an increased number of working days that remained consistent 3 months and 1 year after treatment (Kool, et al., 2005; Kool, et al., 2007; Oesch, Kool, Bachmann, & Devereux, 2006). The workers in the function centered group also had increased lifting capacity and increased self-efficacy. The improvement in self-efficacy is pertinent as both physical and psychosocial risk factors increase the risk of musculoskeletal disorders and affect the likelihood that a worker will return to work and stay there.

When FCE's are used as tools to predict future recovery or future work capacity, they are not as successful. Better floor to waist lifting performance and fewer failed tests in an FCE has been associated with faster recovery, but not with future recurrence (Gross & Battié, 2005b). In addition, FCE performance was not a good predictor of future benefit suspension (Gross &

Battié, 2005a). In fact, the most robust predictor of benefit suspension was the number of health care visits prior to admission into multidisciplinary treatment in that investigation (Gross & Battié, 2005a). Another study also concluded that FCE task performance did not predict future work capacity (Trippolini, et al., 2014b), however, it is not indicated whether the tasks were chosen to match each patient's job demands. Further, the studies that evaluated the predictive validity of FCE's used evaluations from months prior to measurement of work capacity. Regardless, while the predictive validity may not be strong, the use of FCE's as a rehabilitation or work hardening tool appears to have positive results on return to work outcomes.

2.1.6 Current observation criteria

The kinesiophysical approach relies on the observations of the evaluator to determine safe technique through detecting signs of fatigue, changes in coordination and changes in mechanics. It is also the basis of the WWS FCE (Isernhagen, 1992). In a review of FCEs, King, Tuckwell, & Barrett (1998) noted that visual observations can be objective if the evaluators are provided with, and follow, operational definitions of safe mechanics and established scoring criteria for level of effort or impairment. In fact, previous research that investigated different methods to evaluate effort levels during lifting concluded that using physical observations of changes in mechanics successfully differentiated between maximal and submaximal intensities (Lemstra, Olszynski, & Enright, 2004).

Some FCE specific criteria have been developed to identify a safe individual capacity (Table 2), which has helped improve reliability and validity of the results. This criteria has primarily been tested on manual materials handling tasks, while for other types of FCE tasks, like postural tolerance and ambulation, the descriptions of safe mechanics are limited and the available criteria has lower reliability (Trippolini, et al., 2014a; Nicholls, Gibson, McKenna, Gray, & Wielandt, 2011). It should be noted here that "safe" or "unsafe" mechanics is the terminology used to describe movement performance during FCE tasks by other researchers and clinicians, so it will be also be used in this review. However, the purpose of this project will not be to unequivocally identify safe mechanics, but to develop an understanding of movement to guide evaluations.

Table 2: FCE observational criteria for manual materials handling tasks based on the Isernhagen Work Systems FCE from Reneman et al. (2005).

	Light	Moderate	Heavy	Maximal
Muscle Recruitment	Prime movers only; non accessory muscles, no trunk and neck stabilizers	Recruitment of accessories muscle and trunk and neck stabilizers	Pronounced recruitment of accessory muscles and trunk and neck stabilizers	Bulging of accessory muscles and trunk and neck stabilizers
Base of Support	Natural stance	Stable base	Wider base	Very solid base
Posture	Upright posture	Beginning of counter balance	Increasing counter balance	Marked counter balance
Control and movement pattern	Easy movement patterns	Smooth movements	Begins to use momentum. Difficult but not maximal	Uses momentum in controlled manner. Unable to control if weight is added

For tasks that do not involve increasing intensity level, it is imperative that evaluators understand normal and/or safe movement in order to better classify abilities. Trippolini et al. (2014a) has provided some guidelines for non-materials handling with the categories of 1) no or slight functional problem, 2) some functional problem/limitation, or 3) substantial functional problem/limitation (Table 3). Classification of movement into these categories requires identifying deviation from normal posture but normal posture is not explained or described. Normative kinematic data provide a baseline of normal movement or postures, and deviations from these could indicate functional problems or limitations.

Table 3: FCE observational criteria for non- manual materials handling tasks based on the Isernhagen Work Systems FCE from Trippolini et al. (2014).

	No or slight functional problem/limitation	**Some functional problem/limitation**	**Substantial functional problem/limitation**
Posture	Maintains normal posture or slight deviation in posture	Some deviation from normal posture, occasional change in position	Substantial deviation from normal posture, substantial unrest (frequent change in position)
Movement Pattern	Normal movement pattern, slight deviation from normal, smooth movements or slight muscle stiffness, normal to slightly slower performance	Some deviation from the normal movement pattern, tense movements, markedly slower performance	Substantial deviation from the normal movement pattern, very tense movements, very slow performance
Muscle Recruitment	Normal recruitment of prime movers only, or minimal recruitment of accessory and stabilizing muscle of the trunk, neck or joint stabilizers	Some recruitment of accessory and stabilizing muscles of the trunk, neck or joint stabilizers	Pronounced recruitment of accessory and stabilizing muscles of the trunk, neck or joints

2.2 Observation based motion analysis

Observation based analysis a common technique used by clinicians and ergonomists for evaluating all types of clinical populations and workplace factors. Observation is considered a key element of medical decision making (Shapiro, Rucker, & Beck, 1988) and clinicians often use observation of their patients to gather information, make recommendations, and plan interventions. Observation based posture analysis is just as prevalent in the field of ergonomics. Several different observations tools and postural risk categories have been developed (McAtamney & Corlett, 1993; Hignett & McAtamney, 2000; Genaidy, Barkaw, & Christensen, 1995; Callaghan, Jackson, Andrews, Albert, & Potvin, 2003) because this strategy for data collection is low cost, large capacity, and versatile.

Observation based analysis of postures and motions is thought to be a surrogate of joint load and muscular work (Aaras, 1988) as certain movements or postures are related to these variables. For instance, it is well known that postures with a high amount of arm elevation increase load on the shoulder or that high velocity movements require substantial co contraction, resulting in high compression forces and muscular load. Therefore, identifying high risk movements or deviations from normal posture allows evaluators to gain an understanding of how certain tasks or tests affect each patient. However, the ability of clinicians and physiotherapists to detect aberrations or categorize working postures has mixed results (Hickey, Milosavljevic, Bell, & Milburn, 2007; Lowe, 2004a; Lowe, 2004b). Nonetheless, it has also been suggested that observer training can improve accuracy and decision making when classifying postures (Weir, Andrews, van Wyk, & Callaghan, 2011). The normative kinematic profiles obtained in this study, as well as analysis of the profiles with readily available rating scales, will provide guidance to evaluators during and FCE with the goal to improve observation accuracy and subsequent return to work decisions.

The Rapid Upper Limb Assessment, NIOSH Observation Based Posture Assessment and the stressfulness rating scale from Genaidy et al. (1995) were used to evaluate and provide context to the normative kinematic profiles for the selected tasks.

2.3 Need for normative data to identify pathology

2.2.1 Normative data for FCEs

Normative data has been compiled for maximum capacity of many FCEs. Three tasks that largely involved the upper extremity from the Baltimore Therapeutic Equipment Work Simulator were tested. The BTE is a machine-based testing protocol, involving different attachments with output being measured digitally, so only torque, work and power was provided for comparison (Bhambhani, Esmail, & Brintnell, 1994). The overhead reach task required significantly higher torque, work and power than wheel turn or push-pull tasks, however the physiological responses like oxygen uptake, heart rate and gross energy cost were not different between the tasks. Only 3 males between the ages of 18 and 39 were included in this study, so its usefulness as a normative data set is limited. Additionally, a modified WWS FCE has been used to collect normative capacity data from 701 subjects in the form of kilograms or seconds. Subjects were classified by their Dictionary of Occupational Titles (U.S. Department of Labor, 2015) category (sedentary, light, medium, and heavy/very heavy), so the data collected could be to compare persons within the same category. Data were not reported by age or sex although the authors noted that the capacity of some tests largely depends on those factors (Soer, et al., 2009). Notably, the tasks evaluated included the five tasks that were measured in the current investigation but this dataset does not have any indication of mechanics and therefore does provides limited resolution of the abilities of the subjects.

Recently, expert opinions regarding the use of normative capacity data related to FCEs were explored. Experts agreed that normative capacity data were useful for comparing work ability to job demands or treatment goals, for guidance in goal setting in rehabilitation, as a part of determination of work ability in disability claims and as a motivator for treatment when the patient's performance was better than normative values (Soer, Reneman, Frings-Dresen, & Kuijer, in press). Conversely, normative capacity values were perceived as not useful for determining sincerity of effort and potential deterrents during rehabilitation if the patient scored below the norm (Soer et al., in press). However, normative kinematic data would be useful as a comparison for determining performance and work ability, assessing sincerity of effort, and also providing motivation. If patients perform with safe mechanics confidence of a safe return to work is raised, potentially with more training. If their mechanics are not safe, then the normative kinematic data can provide direction to further treatment.

2.2.2 Known movement differences between healthy and shoulder-injured individuals

Injured individuals adopt different movement patterns than healthy controls, possibly to compensate for the injury and save injured structures from further exposure. These proposed compensatory mechanisms are detrimental because they increase the load on uninjured structures that are not normally used for that purpose. Kinematics of healthy compared to pathological populations have been researched in gait and trunk movements and demonstrate this phenomena. For instance, Winter (1991) listed several possible atypical gait patterns that would indicate pathologies, such as forefoot initial contact, stiff-legged weight bearing, a rigid during stance phase and hip hiking during the swing phase. Other researchers have discovered reductions in range of motion, peak angles, and peak moments at the knee and hip in patients with osteoarthritis and anterior cruciate deficiencies (Hurwitz, Hulet, Andriacchi, Rosenburg, & Galante, 1997; Berchuk, Andriacchi, Bach, & Reider, 1990), while one study was able to classify patients into 11 low back pain categories purely based on kinematic variables (Marras, et al., 1993). However, the description of kinematic differences between healthy and shoulder-injured individuals is not as robust.

Shoulder pain has been shown to cause changes in movement strategy on a global level. For instance, Lomond and Coté (2010, 2011a) demonstrated that in a generic repetitive reaching task, range of motion trade-offs were present in injured patients. Compared to healthy subjects, those with shoulder pain used a more a fixed arm strategy during repetitive reaching, meaning they drastically decreased movement variability and shoulder and elbow ROM while still being able to perform prescribed tasks, albeit for a shorter period of time. During hammering, shoulder-injured individuals also demonstrated a fixed strategy at the wrist and elbow (Coté, Raymond, Mathieu, Feldman, & Levin, 2005). The stereotypical motion demonstrated by the injured individuals is detrimental because they may not be able to benefit from the redundancy of the degrees of freedom of the human body and the structures being used instead have an increased level of exposure (Mathiassen, Moller, & Forsman, 2003).The increased exposure can lead to further injuries. In addition, increased center of mass and trunk range of motion has been observed as a compensatory strategy to address the decreased ROM at the shoulder and elbow to maintain performance level during reaching (McClure, Michener, & Karduna, 2006; Roy, Moffet, & McFadyen, 2008; Lomond & Cote, 2011a). These changes may reflect a pain-minimizing strategy by reducing exposure to injured body structures. However, this would increase the demand on the areas being used to compensate.

Differences in scapular kinematics, or scapular dyskinesis, as an identifier of the presence or risk of injury has also been a topic of interest for several researchers. More specifically, kinematic alterations due to rotator cuff injuries, such as impingement syndrome, have been quantified. For patients with subacromial impingement syndrome, compensatory mechanisms can manifest as increased scapular elevation, upward rotation and clavicular retraction (Lin, Hsieh, Cheng, Chen, & Lai, 2011; McClure, Michener, & Karduna, 2006). Both increased and decreased posterior tipping has been observed (Borstad & Ludewig , 2002; McClure, Michener, & Karduna, 2006; Lin, Hsieh, Cheng, Chen, & Lai, 2011), which can have significant effects of shoulder health; inadequate posterior tipping would limit the subacromial space that can cause an increase in impingement symptoms. Nonetheless, all authors noted while the differences were statistically significant, they were very small. In fact, McClure et al. (2006) stated that all the differences in observed in scapular kinematics were less than 5°. Considering that a difference of at least 5° is necessary to be clinically relevant, the adaptations at the scapular level are likely not useful for evaluators observing mechanics during an FCE. As a result, scapular kinematics will not be considered in this investigation.

While there has been some research describing how shoulder-injured individuals use different movement strategies than healthy populations, the relative mechanics of a healthy, non-fatigued population at varying levels of effort and the mechanics of pathological populations during FCE tasks is yet to be determined. The first step to understanding the difference between pathological and healthy movement strategies is to investigate and describe the kinematics of the healthy population. The normative data can subsequently be used to identify injured individuals and to direct treatment.

2.3 Return to work, FCE and the upper extremity

The use of the FCE in return to work decisions for upper extremity disorders is not well documented. Only a few investigations have studied procedures of the WWS FCE for upper extremity evaluation (Reneman, Soer, & Gerrits, 2005; Gross & Battié, 2006) and performance on the upper extremity focused tasks of the FCE was only a weak predictor of faster return to work and did not relate to sustained recovery, according to one study (Gross & Battié, 2006). In fact, lifting performance was identified as the best indicator of return to work from the FCE protocol for any type of injury (Gross & Battié, 2006; Gross & Battié, 2003), which could be inflated due to the disproportionate amount of previous research regarding the testing criteria for lifting tasks, allowing the criteria to be more refined than the guidance for other FCE portions. Thus, current FCE protocols for evaluating the upper limb may be too obtuse to be useful in determining ability to return to work. Further investigation into kinematics during upper extremity focused tasks may improve FCE outcomes for persons with upper extremity injuries.

This investigation will address the lack of guidance for upper extremity evaluation during an FCE by producing normative data for common FCE tasks focused on upper extremity evaluation. These data can be used by evaluators of varying skillsets to determine if a patient's kinematics are typical or atypical. This information can direct treatment, help identify injury mechanisms, and provide the basis of RTW decisions.

Chapter 3: Methods

3.1 Participants

Thirty participants (15 males, 15 females) were recruited from a convenience sample. Both sexes were recruited to obtain normative data applicable to a larger portion of the working population and determine gender specific movement compensations. Participants were recruited using posters or verbal recruitment. Exclusion criteria included upper extremity pain during functional tasks or previous injuries to their upper extremity in the last six months.

Before any data was collected, participants filled out a QuickDASH questionnaire (Appendix A) to evaluate arm, shoulder or hand disability. Participants also filled out a Physical Activity Readiness Questionnaire (PAR-Q) (Appendix B) to ensure they would be able to safely participate in the level of physical activity required to complete these tasks. The purposes, risks and benefits of this study were explained and they signed a consent form if they chose to continue. Participants received $25 upon the completion of the session.

3.2 Instrumentation

3.2.1 Motion Capture

All movements were tracked using 8 VICON MX20 (Vicon Motion Systems, Oxford, UK) optoelectronic infrared cameras positioned around the collection space. Twenty-two individual passive reflective markers were placed on the skin near bony anatomical landmarks on the arm, torso and head. Additionally, five rigid clusters (totaling 17 markers) were placed on the upper extremities. The position of the markers were sampled at 50 Hz.

Table 4: Anatomical landmark locations of individual markers

Marker	Description
SS	Suprasternal notch
C7	Spinous process of the 7th cervical vertebra
XP	Xiphoid Process
T8	Spinous process of the 8th thoracic vertebra
AR*	Acromion
ME*	Medial epicondyle of the humerus
LE*	Lateral epicondyle of the humerus
RS*	Radial styloid
US*	Ulnar styloid
MC2*	2nd metacarpal phalangeal joint
MC5*	5th metacarpal phalangeal joint
IC*	Iliac crest
GT*	Greater trochanter of the femur

*Indicates bilateral placement

Table 5: Marker cluster locations

Marker	Description
UA1*	Upper Arm cluster (placed at approximately halfway up the humerus)
UA2*	
UA3*	
FA1*	Forearm cluster (placed approximately halfway up the forearm)
FA2*	
FA3*	
P1	Pelvis cluster (placed on the sacrum)
P2	
P3	
P4	
P5	

*Indicates bilateral placement

3.2.2 Ratings of Perceived Exertion

The perceived exertion of the participant was measured using the CR-10 Exertion Scale (Borg, 1982) (Appendix C). Perceived exertion was used to estimate the subjective level of effort of each participant before and after each set of each task. Tests were terminated if the participant rated the task to be a 10 before the final set. Participants could also voluntarily terminate the test due to pain or discomfort before a maximal effort Borg scale rating is reached.

3.3 Experimental Protocol

Participants performed five tasks (Figure 1) that targeted upper extremity motions based on the WWS FCE protocol (Reneman, Soer, & Gerritis, 2005; Gross & Battié, 2006). The duration of each testing session was approximately two hours. The selected tasks allowed analysis of mechanics and capacity during manual materials handling, postural tolerance, coordination, and repetition tasks (Soer et al., 2009). Tasks were selected because the procedures are safe and easily administered by the researchers, the reliability of most tasks is established, the costs were low and the equipment was readily available.

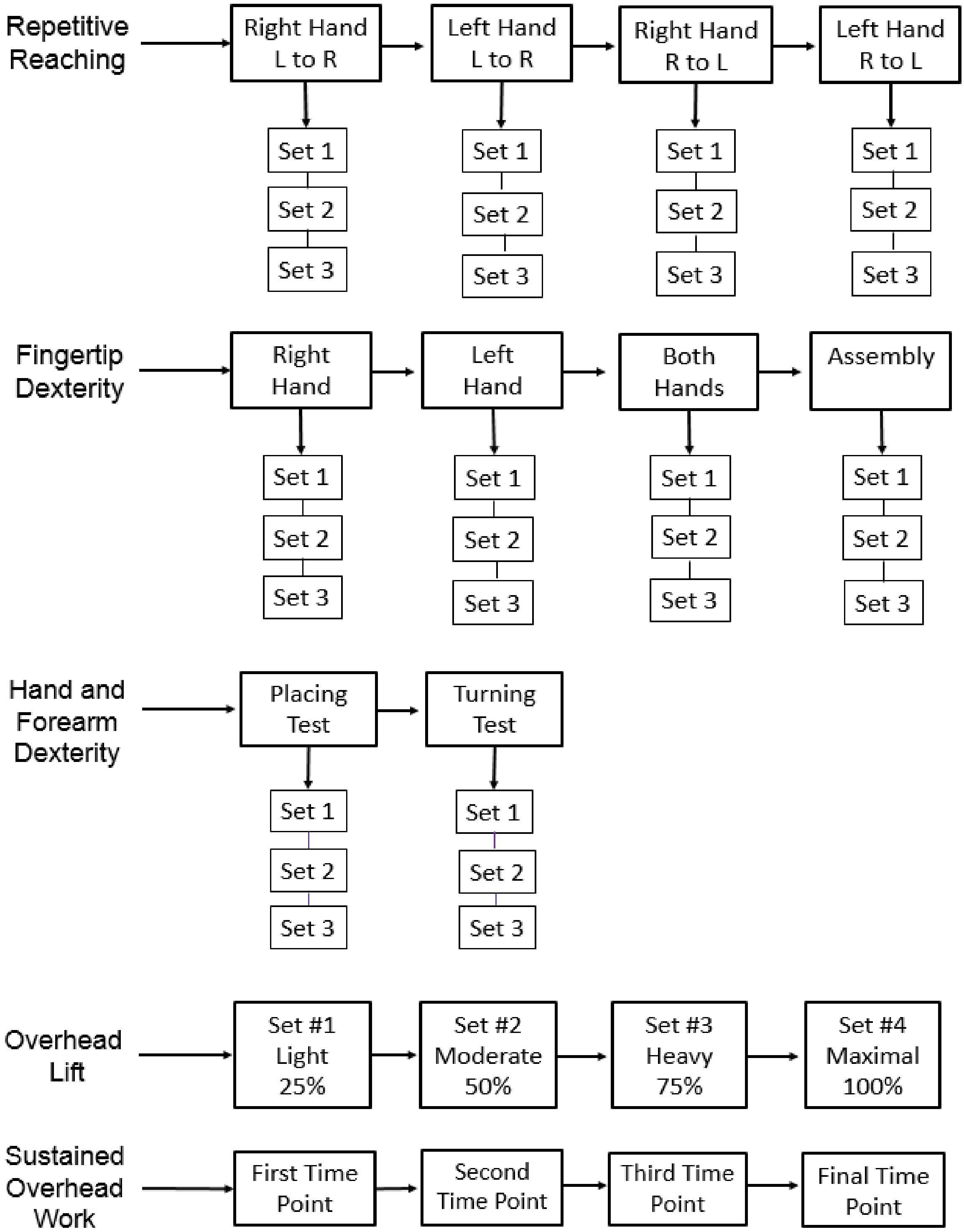


Figure 1: Set up of tasks and sets in protocol. The 5 tasks were performed in the order listed above to minimize the effects of fatigue. RPE scores were taken before and after each set.

After the participants provided informed consent, filled out the QuickDASH and PAR-Q, they performed a static strength test to estimate loads for the overhead lifting task. The test began with several repetitions of overhead lifting with a light weight for warm up. The strength test was a static lift with the arms flexed (Chaffin, Andersson, & Martin, 2006). A push/pull dynamometer was attached by chain to a platform that the subject stood on. The chain was adjusted so participant's elbows will be flexed at 90^{o} when holding the handle (Figure 2).

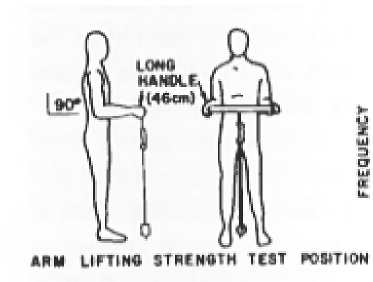


Figure 2: Static strength test posture
(Chaffin, Andersson, & Martin, 2006)

The participant then performed 3 maximal static lifts in this position and the highest value was considered the 1 repetition maximum (RM). This value was used in a 1 RM prediction equation (Eq. 1) to predict the 5 RM (LeSuer, McCormick, Mayhew, Wasserstein, & Arnold, 1997).

$$1RM = 100 * rep\ wt/(102.28 - 2.78 * reps) \quad (1)$$

Participants then performed one test lift of the predicted 5RM load and the load was adjusted based on the participant's estimate of their ability to lift the load five times. The load for the 3 others sets was calculated at 25%, 50%, and 75% of the 5RM weight. The purpose of setting the loads in this way was to ensure that all participants worked at the desired intensity during each set.

Following the prediction test, the participants received 10 minutes rest before starting the protocol (LeSuer, McCormick, Mayhew, Wasserstein, & Arnold, 1997) during which they were outfitted with markers for motion capture.

During a FCE in a clinical setting evaluators often start with the least strenuous tasks and end with the most strenuous, and this type of approach that was taken in this study to decrease effects of fatigue on kinematics. The order of the tasks was consistent: repetitive reaching, fingertip dexterity, hand and forearm dexterity, overhead lifting, and finally sustained overhead working. Participants rested for a minimum of 1 minute between sets with additional rest time if desired (Parcell, Sawyer, Tricoli, & Chinevere, 2002), but extra rest time was not requested by any participants. They were instructed to perform each task to their voluntary maximum capacity but informed that they could end the test at any time if they were feeling pain or discomfort. A familiarization period preceded each task. A perceived exertion rating was recorded before and after each set of each task.

3.3.1 Repetitive Reaching Task (RRT)

The first task was the repetitive reaching task; this task represents manual materials handling tasks that focus on coordination and speed of movement. The standard objective of this test is to evaluate the speed of repetitive movements of the upper extremity (Reneman et al., 2005) and the outcome is the time required to move 30 marbles.

Materials: This task required 30 marbles and 2 bowls (14 cm diameter) positioned on a table adjusted to the participant's just below elbow height based on the NIOSH light MMH guidelines (Cohen, Gjessing, Fine, Bernard, & McGlothlin, 1997).

Procedure: The bowls were separated by the wingspan of each participant (Figure 3). While sitting, the participant moved the marbles horizontally from one bowl to the other in both directions and with each arm, for a total of 4 different subtasks:

1. Right Hand, Left to Right
2. Left Hand, Left to Right
3. Right Hand, Right to Left
4. Left Hand, Right to Left

Each subtask was repeated 3 times. The participant was instructed to move the marbles as quickly as possible and to keep the arm not being tested resting on the table. The measurement of performance was the average time of all 3 sets of each subtask.

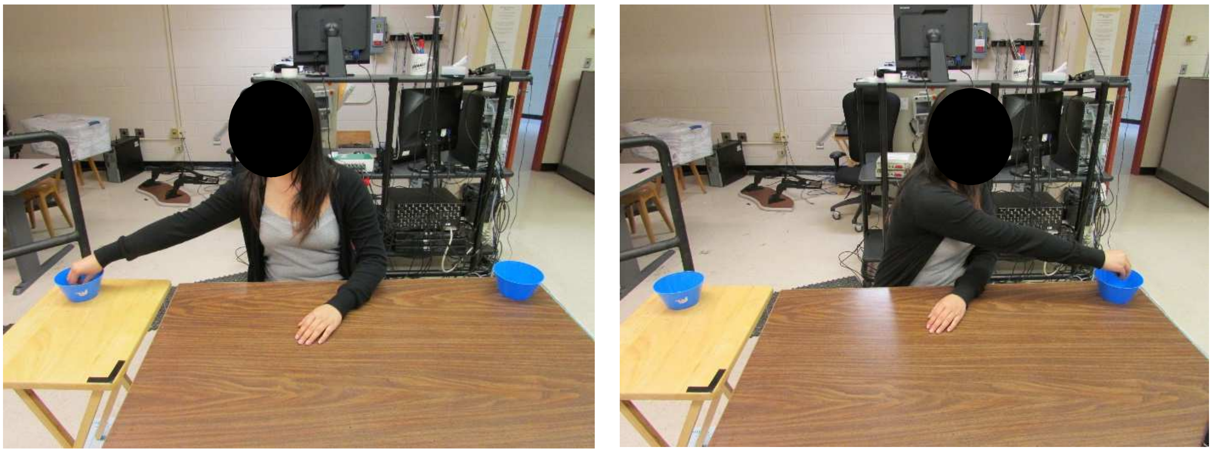


Figure 3: One cycle of the Right Hand, Right to Left subtask of the Repetitive Reaching task. The bowls are placed at the participant's wingspan and they will move 30 marbles from the first bowl to second bowl with one hand.

Verbal Instructions: The goal of this task is to move all 30 marbles from bowl to the other as quickly as possible. All three trials of each subtask will be performed before moving on to the next subtask.

Start with both hands resting on the table. One hand will move at a time and the other hand will remain on the table. Keep both feet planted during each trial and if you drop a marble, just keep going.

3.3.2 Fingertip Dexterity Task (FD)

The standard objective of the task is to evaluate fingertip dexterity; however, it also tests the speed of movement of the upper extremity and gross movements of the fingers, hands and arms (Lafayette Instrument, 2002). The test is scored based on how many pins the subject places in the pegboard in a set period of time.

Materials: The Purdue Peg Board Test (Lafayette Instrument, IN) was used for this task. It includes a peg board with 2 vertical rows of holes, and pins, washers, and collars that are located along the top of the board (Figure 4). The test apparatus was positioned on a table adjusted to just below the participant's elbow height when sitting (Cohen, Gjessing, Fine, Bernard, & McGlothlin, 1997).

Figure 4: Overhead view of the Purdue Pegboard (Lafayette Instrument, 1999) used for the fingertip dexterity task.

Procedure: The participant sat in front of the peg board and placed the pins as quickly as possible into the holes in 4 different subtasks (Figure 5). Each subtask was repeated 3 times, as is standard for the Purdue Pegboard protocol (Lafayette Instrument, 2002).

1. Right Hand - The subject picked up a pin with their right hand and placed it in the right side of peg board as many times as they could in 30 seconds.

2. Left Hand - The subject picked up a pin with their left hand and placed it in the left side of peg board as many times as they could in 30 seconds.
3. Both Hands – The subject performed this task with both hands moving at the same time; the subject simultaneously picked up pins with the right and left hands and placed them in the pegboard as quickly as they can for 30 seconds.
4. Assembly - This assembly task requires both hands. The subject placed a pin in the board with their right hand, put a washer on top with their left hand, followed by a collar with their right hand and another washer with their left. Each assembled piece counts as four points and the total score is the total numbered of assembled pieces in 60 seconds, multiplied by four.

The final performance measure was the average score of all three sets of each subtask.

Figure 5: The Right Hand (left), Both Hands (middle), and Assembly (right) tasks of the Purdue Pegboard. The Left Hand task mirrors that of the Right Hand.

Verbal Instructions: The verbal instructions given were those provided with the Purdue Pegboard (Appendix D).

3.3.3 Hand and Forearm Dexterity Task (HFD)

The hand and forearm dexterity task evaluates the gross movement coordination of the fingers, hands and arms (Renemen et al., 2005). The outcome of this test is the total time required to move the blocks in a predetermined way.

Materials: The Minnesota Manual Dexterity Test (MMDT) (Lafayette Instrument, IN) was used for this task. It includes 60 disks and a folding board with 60 round holes (Figure 6). The test was positioned on table adjusted to the same height as the two previous tests.

Figure 6: Minnesota Manual Dexterity Test (Lafayette Instrument, 1999) used for the hand and forearm dexterity task.

Procedure: The MMDT is comprised of 2 test batteries: the placing task and the turning task. Another version of the test is available, the complete MMDT which involves five different tasks, but just the placing and turning tasks were chosen as they have been previously investigated (Surrey, et al., 2003). Each subtask was repeated three times.

The participant sat in front of the MMDT. Participants were instructed to move the blocks as quickly as possible in each task and the total time to complete each task was recorded.

The placing task involved only the use of the dominant hand and required the participant to move the disks from 10 inches away from the edge of the table to the board that was one inch from the edge of the table (Figure 7). The first block was moved from the bottom right corner of the blocks to the top right corner of the board. The next disk was taken from directly above the empty spot in the right column and moved directly below the disk on the bottom board. This pattern continued until all the disks were moved (Lafayette Instrument, 1999).

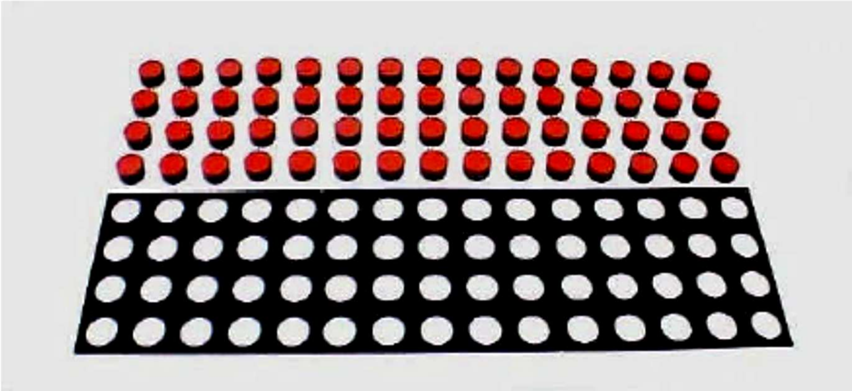


Figure 7: Starting position for the Placing task (Lafayette Instrument, 1999)

The Turning task required the board to be placed 1 inch from the edge of the table with all disks inserted into the holes and the red side facing up. The participant then picked up the disk in the top right hand corner using their left hand and turned it over while passing it to the right hand. They then returned the disk to the original hole with their right hand with the black side facing up. This pattern was repeated across the top row, moving to the left. For the second row, the participant picked up the disk using their right hand and put it down with their left, moving to the right. The third row was the same procedure as the first row, while the fourth row was the same as the second (Figure 8) (Lafayette Instrument, 1999).

The final performance measure was the total time of all 3 sets of each subtask.

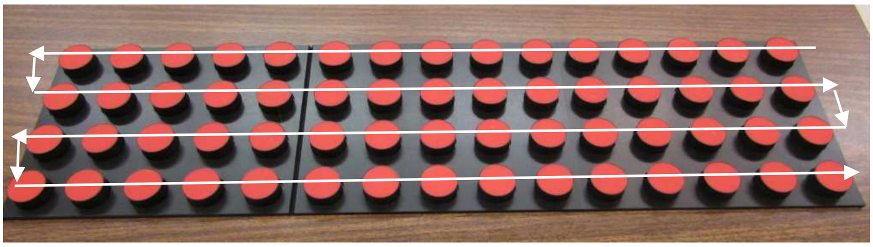


Figure 8: Starting position and sequence of rows with direction of movement for the Turning task.

Verbal Instructions: The verbal instructions given were those provided with the Minnesota Manual Dexterity Test procedures (Appendix E).

3.3.4 Waist to Overhead/Crown Lift (OL)

The waist to overhead lift is a common manual materials handling task. In a standard FCE, this task is used to evaluate the participant's capacity to lift high and to evaluate the functional strength of the upper extremity musculature (Reneman, Fokkens, Dijkstra, Geertsen, & Groothoff, 2005). The outcome is the maximum amount of weight lifted.

Materials: A plastic container with varying weights and shelves that was adjusted to the participant's waist and forehead height.

Procedure: The lifting procedure from the WWS FCE requires the participant to do four sets of five lifts from the waist to crown height. Each set must be completed within 90 seconds. They began in a standing position. The first set was 25% of the previously predicted maximum and the weight increased to 50%, 75% and 100%.

Verbal Instructions: Grab the milk crate with both hands. Lift the crate to the top shelf five times in a row within 90 seconds. Brace your core and focus on using your arms. You can step or rock back to as you lift the crate up to keep the crate in a straight line. To bring the crate down, you can step or rock back as you lower the crate.

3.3.5 Sustained Overhead Work (OW)

Overhead working evaluates the postural tolerance capacity of the participant as well as their strategies to maintain the posture. The outcome of this test is usually the total time that the position is held.

Materials: The task requires a shelf adjusted to forehead height, nuts and bolts and 1 kg cuff weights.

Procedure: The participant stood in front of the shelf wearing the cuff weights. They manipulated nuts and bolts until they could no longer hold the desired position. They were instructed to not let their arms drop for the duration of task. The test was terminated when the participant could no longer maintain the posture, or if the ceiling of 15 minutes was reached (Reneman, et al., 2004). Verbal ratings from the modified Borg scale were taken every minute for the duration of the task.

Verbal Instructions: The purpose of this test is to perform the task for as long as you can. Stand in front of the shelf and pick up the nuts and bolts. Screw and unscrew the bolts for as long as you can. You use whichever bolt you like and switch at any time but do not let your wrists or forearms rest on the shelf. You must keep your hands at the level of shelf – do not let them drop lower than the height of the shelf. Every minute you will be asked your RPE rating. You can stop the test at any time but try to go as long as possible. There is ceiling of 15 minutes.

3.3.6 Experimental Variables

Comparison variables for this investigation were sex and performance. The measure of performance will differ depending on the task (Table 6).

Table 6: Independent variables by task.

Task	Comparison Variables
Repetitive Reaching	Sex
Finger Dexterity	Sex
Hand and Finger Dexterity	Sex
Overhead Lift	Sex, intensity
Overhead Work	Sex, time block

The dependent variables of this investigation included aspects of movement that are the most likely to be observable during an evaluation:

1. The mean angle of the wrist (bilateral flexion/extension, radial/ulnar deviation), elbow (bilateral flexion/extension, pronation/supination), thoracohumeral (bilateral plane of elevation, elevation, internal/external rotation), and trunk (flexion/extension, rotation, lateral flexion).
2. Maximum and minimum angles for the same joints and axes as mentioned above.
3. Resultant mean and peak velocity of each segment

3.4 Data Analysis

3.4.1 Identifying Cycles

To analyze the kinematics of these tasks, movement cycles were defined within each trial. For all subtasks and sets of the repetitive reaching, fingertip dexterity, and hand and forearm dexterity tasks, a movement cycle was defined as the time during which the arm moved from the starting position and back, which was dependent on the task or subtask being performed. For example, in the repetitive reaching task a cycle was defined as when the participant picks up the marble in the first bowl to when the hand returns to the first bowl to retrieve the next marble. For the fingertip dexterity and hand and forearm dexterity placing tasks, a cycle began when the participant picked up the pin or block and ended when the hand returned to the grab the next pin or block. The hand and forearm dexterity turning task did not have identifiable cycles so the entire trial was analyzed as one cycle. For the overhead lift, a cycle was defined as the time during which participant picked up the box from the low shelf with both hands and placed it on the high shelf. The participant had to lower the box during the task, but only the lift portion was analyzed.

All cycles were identified through the use of equipment reference markers. An equipment calibration was performed prior to task performance during which reflective markers were placed at the position of the equipment for each task (i.e. the bowls for the repetitive reaching task, the edge of the pin storage in the fingertip dexterity task, etc.). Cycles were identified by locating when the hand markers passed the value of the position of the marker in the direction of movement. For example, for the fingertip dexterity, the equipment calibration was done by placing markers at the edge of the pin storage area and then the X value of the marker was extracted (Figure 9).

Every time the hand marker passed the X value during the trial, the frame number was determined and used to create cycles. All cycles were rubber banded and ensemble averaged within each set, with the exception of the hand and forearm dexterity placing task.

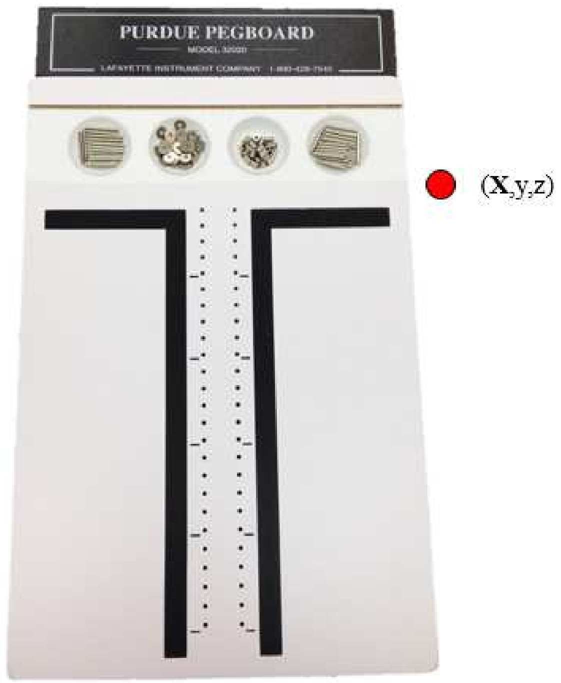


Figure 9: Diagram of equipment calibration for the fingertip dexterity task. A reflective marker (represented by the red dot) was placed at the base of the pin storage area and the position of the marker in the X direction was extracted, because movement is largely in the X direction for this task. Every time the hand markers passed the position of the marker, it signaled the start or end of a cycle.

In the placing task, there were four levels of positions for blocks (Figure 10). Only cycles during in the blocks from the highest level were moved were averaged. This task was also broken up into thirds and cycles within each third were ensemble averaged. For the repetitive reaching, fingertip dexterity, and hand and forearm dexterity tasks, all sets within a subtask were averaged and comparisons were made between sexes. Differences in the overhead lift were also analyzed at each intensity level.

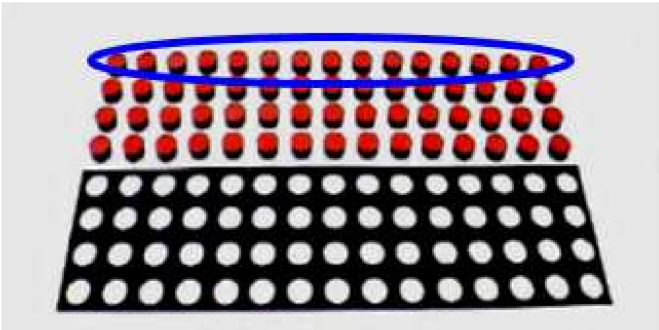


Figure 10: Hand and forearm dexterity place task set up. For this subtask, only the cycles involving movement of the blocks in the row circled in blue were used for analysis.

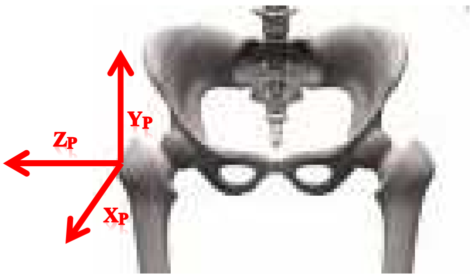
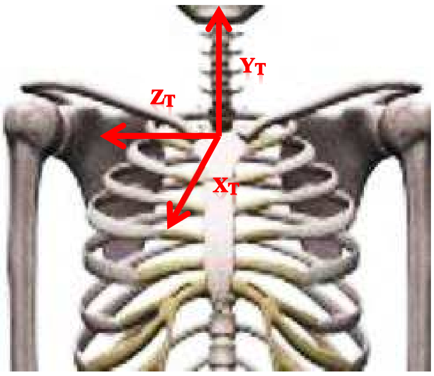
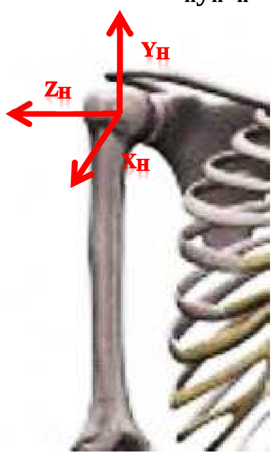
Finally, the overhead work did not have defined cycles, but the first 30 seconds, last 30 seconds and 2 sets of 30 seconds from the middle of the task were selected for analysis. The time points selected in the middle depended on the total length of the task and were evenly spaced apart from each other, the first point, and last time point. For example, if the participant performed the task for 8 minutes, the first time point would be from 0-0:30, second would be from 2:30-3:00, third would be from 5:00-5:30, and the last would be from 7:30-8:00. One participant only performed the task for 86 seconds and was subsequently removed from analysis. Kinematic differences between each time point were analyzed.

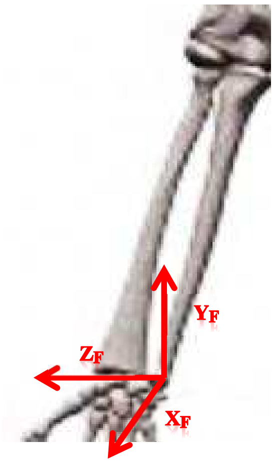
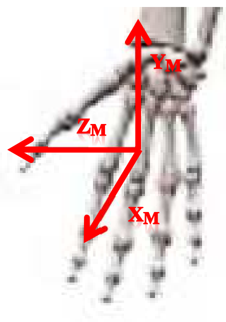
3.4.2 Kinematics

Kinematic data were processed with a custom MATLAB® code. All raw kinematic data were filtered with a low pass zero-lag fourth order Butterworth filter with a 6 Hz cutoff (Winter, 2009). The filtered data were used to create local coordinate systems of each segment (Table 7). The local coordinate systems were based on the recommendation made by the International

Society of Biomechanics (Wu, et al., 2005). ISB standards are described for only the right side of the body, so the left humerus, forearm and hand the local coordinate systems were the same but the joint rotation interpretation was different. Three non-collinear anatomical landmarks on each segment were used to construct the local coordinate systems. For the humerus, the glenohumeral joint was used as a landmark and was calculated as 60 mm below the acromion marker parallel to the Y vector of the torso (Nussbaum & Zhang, 2000).

Table 7: The local coordinate systems of each segment as recommended by ISB standards *(Wu, et al., 2005)*

Body Segment	Origin	Local Coordinate System
Pelvis – $x_py_pz_p$  	RGT	**y_p:** line connecting the midpoint between RGT and LGT and the midpoint between RIC and LIC, pointing upward **x_p:** line perpendicular to the plane formed by RIC, LIC and the midpoint between RGT and LGT, pointing forward **z_p:** the common line perpendicular to the x_p- and y_p- axis.
Thorax - $x_ty_tz_t$  	IJ	**y_t:** line connecting the midpoint between XP and T8 and the midpoint between IJ and C7, pointing upward **z_t:** line perpendicular to the plane formed by IJ, C7, and the midpoint between XP and T8, pointing to the right **x_t:** the common line perpendicular to the x_t- and y_t- axis.
Humerus – $x_hy_hz_h$  	GH	**y_h:** line connecting GH and the midpoint of EL and EM, pointing to GH **x_h:** line perpendicular to the plane formed by EL, EM, and GH, point forward **z_h:** the common line perpendicular to the x_h- and y_h- axis.

<table>
<tr><td>Forearm – $x_f y_f z_f$

</td><td>US</td><td>y_f: line connecting US to the midpoint between the EL and EM, pointing proximally
x_f: line perpendicular to the plane through US, RS and the midpoint between EL and EM, point forward
z_f: the common line perpendicular to the x_f- and y_f- axis.</td></tr>
<tr><td>Hand – $x_m y_m z_m$

</td><td>Midpoint of the 3rd metacarpal</td><td>y_m: line parallel to a line from the center of the distal head of the third metacarpal to the midpoint of the base of the third metacarpal
x_m: line that forms a sagittal plane with y_m and splits the metacarpal into mirror images
z_m: the common line perpendicular to the x_m- and y_m- axis.</td></tr>
</table>

Joint coordinate systems were used to describe clinically relevant rotations. Trunk rotations were calculated relative to the pelvis coordinate system as flexion/extension, lateral flexion, and axial rotation. Thoracohumeral (humerus relative to the thorax) rotations were described as abduction/adduction, flexion/extension, and internal/external rotation (Phadke, Braman, LaPrade, & Ludewig, 2011). Elbow rotations were described as flexion/extension and pronation/supination, while wrist rotations were flexion/extension and ulnar/radial deviation. Euler decompositions were used based on the ISB recommendations from Wu et al. (2005), with the exception of the humerus rotation sequence, which was chosen to reflect more clinically relevant angles and address singularity issues (Table 8).

Table 8: Euler rotation sequences and their clinically relevant interpretations.

Joint	Order	Clinical Interpretation	Rotation Sequence
Thorax (relative to pelvis system)	Z X' Y"	Flexion/Extension Lateral Flexion Axial Rotation	**e1:** axis coincident with Z_P-axis of pelvis system **e3:** axis fixed to the thorax and coincident with y_t-axis of the thorax system **e2:** common axis perpendicular to e1 and e3 (the rotated x_t-axis of the thorax)
Thoracohumeral (humerus relative thorax)	X Z' Y"	Abduction/Adduction Flexion/Extension Axial Rotation	**e1:** axis fixed to the thorax and coincident with x_t-axis of the thorax system **e3:** axial rotation around the y_h-axis **e2:** common axis perpendicular to e1 and e3 (the rotated z_h-axis of the humerus)
Elbow	Z X' Y"	Flexion/Extension Carrying Angle* Pronation/Supination	**e1:** axis fixed o the proximal segment and coincident with Z_h-axis of humerus system **e3:** axis fixed to the distal segment and coincident with y_f-axis of the forearm system **e2:** common axis perpendicular to e1 and e3 (the rotated x_f-axis of the forearm)
Wrist	Z X' Y"	Flexion/Extension Ulnar/Radial Deviation Rotation*	**e1:** axis fixed o the proximal segment and coincident with Z_f-axis of forearm system **e3:** axis fixed to the distal segment and coincident with y_m-axis of the hand system **e2:** common axis perpendicular to e1 and e3 (the rotated x_m-axis of the hand)

*will not be analyzed in this investigation

For all rotations, α is about the z-axis, β is about the x-axis and γ is about the y-axis, regardless of the order of the rotation. These angles were determined by extracting them from the respective transformation matrix and the interpretation was dependent on the joint coordinate system (Table 8). The thorax, elbow and wrist angles were extracted from the transformation matrix derived using the Z-X'-Y" Euler sequence (Equation 2).

$$\begin{bmatrix} \cos\gamma\cos\alpha - \sin\gamma\sin\beta\sin\alpha & \cos\gamma\sin\alpha + \sin\gamma\sin\beta\cos\alpha & -\sin\gamma\cos\beta \\ -\cos\beta\sin\alpha & \cos\beta\cos\alpha & \sin\beta \\ \sin\gamma\cos\alpha + \cos\gamma\sin\beta\sin\alpha & \sin\gamma\sin\alpha - \cos\gamma\sin\beta\cos\alpha & \cos\gamma\cos\beta \end{bmatrix} \quad (2)$$

To describe thoracohumeral motion, a transformation matrix derived using the X-Z'-Y" sequence was used (Equation 3).

$$\begin{bmatrix} \cos\gamma\cos\alpha & \cos\gamma\sin\alpha\cos\beta + \sin\gamma\sin\beta & \cos\gamma\sin\alpha\sin\beta - \sin\gamma\cos\beta \\ -\sin\alpha & \cos\alpha\cos\beta & \cos\alpha\sin\beta \\ \sin\gamma\cos\alpha & \sin\gamma\sin\alpha\cos\beta - \cos\gamma\sin\beta & \sin\gamma\sin\alpha\sin\beta + \cos\gamma\cos\beta \end{bmatrix} \quad (3)$$

The mean and peak angles were extracted from the clinically relevant axes.

Linear velocities of each segment were calculated from displacement data using the finite difference method for each axis (Eq. 4). The resultant vector was calculated and the mean and peak velocities were extracted.

$$v(t) = \frac{dx(t)}{dt} = \frac{x(t) - x\,(t-1)}{\Delta t} \quad (4)$$

3.4.3 Statistical Analysis

3.4.3.1 Descriptive Statistics

The summary statistics of each variable are presented for each task, including mean, maximum and minimum values. Time series joint angle profiles were generated by ensemble averaging all participant curves. The means with +/- one standard deviation for each task or subtask were plotted to create graphical references for the computed profiles (Winter, 2009; Picco, 2012).

3.4.3.2 Analysis of Variance (ANOVA)

For the reaching and dexterity tasks, which only have one intensity level, one-way ANOVAs were used to test sex effects on each dependent variable for each relevant axis. For the waist to overhead lift and overhead work tasks, two-way mixed ANOVAs with interactions were used to assess the influence of the intensity level and sex on the dependent variables for each axis. The independent variables were treated as nominal variables for all ANOVAs. The results from the ANOVAs determined the final method of presenting the data (Figure 11). For instance, there was a main effect of load for the overhead lifting task, so the data were reported by percentage of maximal load as opposed to grouping all trials together.

If a significant effect on kinematics existed ($p<0.05$), a post-hoc Tukey HSD test was performed to confirm the differences and identify which performances resulted in different angular kinematics. However, if there was not a difference of at least 5°, which is considered the smallest changes that are clinically relevant (Ebaugh, McClure, & Karduna, 2005; Ludewig & Cook, 2000), the data were not reported based on the statistically significant differences. The purpose of presenting the data this way was to ensure high utility for FCE evaluators; based on the results of this study, practitioners have guidance when determining what to look for, depending on the sex of the patient and the intensity level, during the observation of upper limb kinematics.

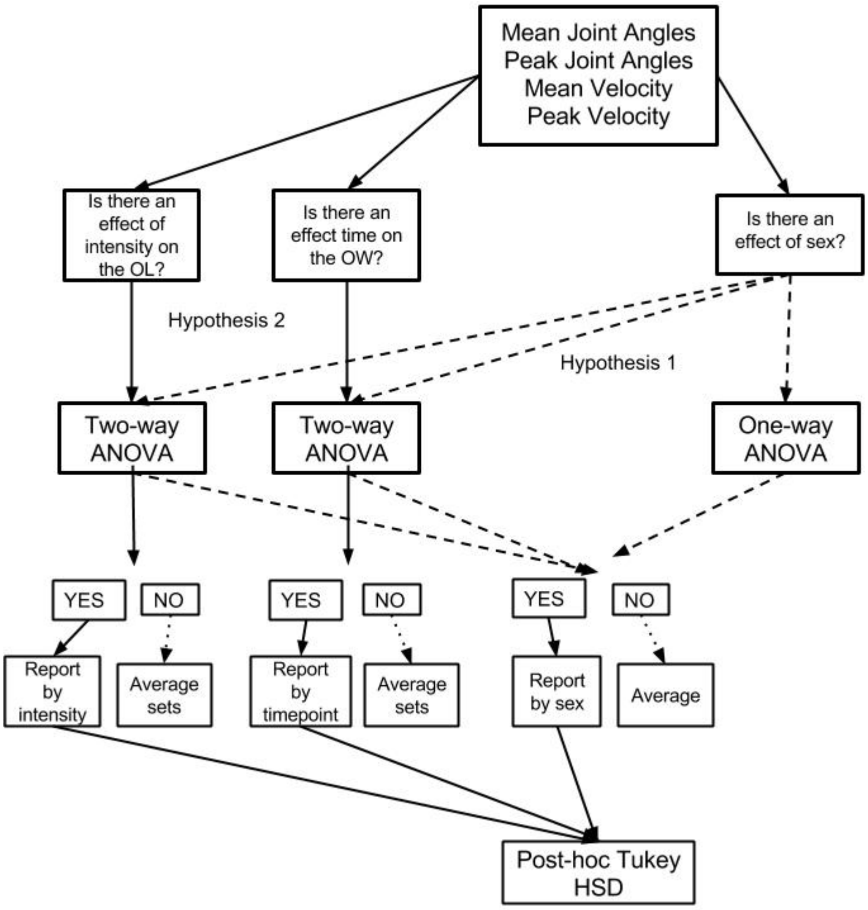


Figure 11: Visual summary of the statistical analysis. Main effects of sex and performance were tested and presented based on the results.

Chapter 4: Results

Thirty young, healthy adults (height = 1.7m, weight= 72.8 kg, age = 23) participated. The average QuickDASH score for all participants was 4.2.

4.1 Capacity

The mean capacity scores measured were equal to or better than the mean scores of corresponding tasks from a larger normative data study (Soer et al., 2009). In addition, the minimum scores of the current study were also always better than the minimum scores of Soer et al. (2009), indicating that the population in this study is likely healthy and free from impairments that would interfere with their work (Table 9).

Table 9: Mean and minimum capacity scores during each FCE subtask of the current study compared to corresponding tasks from the large normative capacity study (Soer, et al., 2009)**.**

Current Study			Soer et al. (2009)		
Task (performance measure)	**Mean**	**Min**	**Task (performance measure)**	**Mean**	**Min**
Repetitive Reaching, Right to Left, Right Hand (s)	55.46	76.0	**Repetitive Reaching, Right Hand (s)**	74.25	112.75
Repetitive Reaching, Right to Left, Left Hand (s)	55.89	82.0			
Repetitive Reaching, Left to Right, Right Hand (s)	54.40	81.33	**Repetitive Reaching, Left Hand (s)**	75.0	112
Repetitive Reaching, Left to Right, Left Hand (s)	56.12	81.67			
Fingertip Dexterity, Right Hand (# of pins)	17.69	14.3	**Fingertip Dexterity, Right Hand (# of pins)**	15.97	11.48
Fingertip Dexterity, Left Hand (# of pins)	16.70	13.0	**Fingertip Dexterity, Left Hand (# of pins)**	15.42	11.38
Fingertip Dexterity, Both Hands (# of pins)	13.91	10.0			
Fingertip Dexterity, Assembly (# of pins)	37.49	26.0			
Hand and Forearm Dexterity, Placing (s)	194.80	242.0	**Hand and Forearm Dexterity, Right Hand (s)**	182.5	253.5
Hand and Forearm Dexterity, Turning (s)	148.52	181.5	**Hand and Forearm Dexterity, Left Hand (s)**	190.25	262.5
Waist to Overhead Lift (kg)	23.67	13.5	**Waist to Overhead Lift (kg)**	18.75	7.75
Overhead Work (s)	285	85.80	**Overhead Work (s)**	262.5	85.75

The only significant capacity difference ($p<.05$) between sexes was the weight lifted in the waist to overhead lift; males lifted significantly more than females. In all other tasks, there was a trend towards females scoring better than males, but these differences were not significant (Table 10).

Table 10: Mean capacity scores for males and females during each FCE subtask. The only significant difference between sexes was in the load lifted in the waist to overhead lift.

Task (performance measure)	Males [mean (SD)]	Females [mean (SD)]
Repetitive Reaching, Right to Left, Right Hand (s)	56.31 (7.47)	54.61 (9.76)
Repetitive Reaching, Right to Left, Left Hand (s)	57.31 (9.65)	54.47 (10.76)
Repetitive Reaching, Left to Right, Right Hand (s)	56.18 (9.01)	52.62 (10.14)
Repetitive Reaching, Left to Right, Left Hand (s)	57.94 (9.07)	54.29 (11.27)
Fingertip Dexterity, Right Hand (# of pins)	17.22 (1.62)	18.16 (1.86)
Fingertip Dexterity, Left Hand (# of pins)	16.29 (1.54)	17.1 (2.32)
Fingertip Dexterity, Both Hands (# of pins)	13.53 (1.33)	14.28 (1.65)
Fingertip Dexterity, Assembly (# of pins)	35.77 (6.47)	39.2 (4.39)
Hand and Forearm Dexterity, Placing (s)	197.13 (21.23)	192.47(20.65)
Hand and Forearm Dexterity, Turning (s)	148.67 (17.46)	148.37 (19.46)
Waist to Overhead Lift* (kg)	29.63 (4.39)	17.7 (2.96)
Overhead Work (s)	261 (89)	309 (211)

*Significant sex difference

4.2 Kinematics

4.2.1 Sex

Kinematic results are presented together for males and females. Some significant differences of the summary statistics between males and females existed but the number of significant outcomes was only 5.4% of the total tests run, which is only slightly higher than the percentage of potential false positives. Thus, due to the high probability that significant findings are due to Type 1 error, all kinematic profiles and intensity differences are presented as an aggregate of males and females (Figure 12).

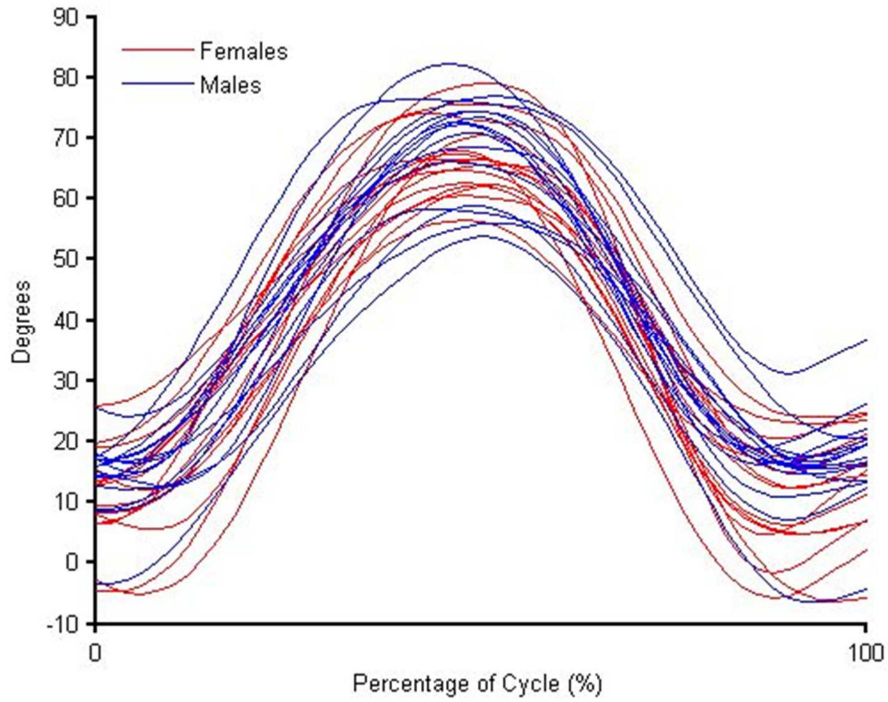


Figure 12: Mean curves of males and females for humeral flexion during the repetitive reaching task. Curves overlap for males and females indicating the similarity of movement between sexes.

4.2.2 Intensity

Intensity had a significant effect ($p<.05$) on kinematics during the waist-to-overhead lift and overhead work tasks.

Across the four loads of the waist to overhead lift task, torso flexion/extension maximum and minimum angles changed significantly (Figure 13). Maximum angle increased by 10.4° (7.10°) and minimum angle decreased by 5.22° (3.62°) from the first to last load. These changes reflect a rise in both flexion and extension as load increased. Mean torso angle also increased significantly, but by less than 5°.

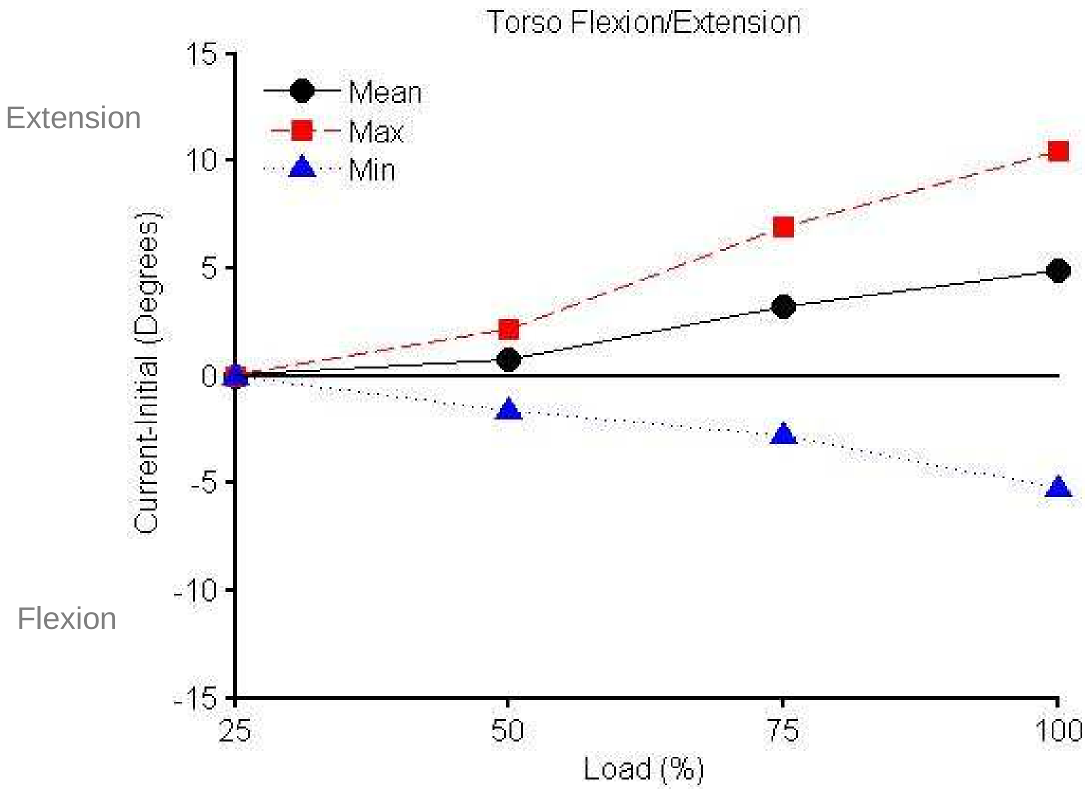


Figure 13: Torso flexion/extension angle change from initial for the waist to overhead lift. The decreasing minimum angle reflects increasing torso flexion, while increasing maximum angle increasing torso extension.

Both right and left arm humeral flexion also changed with intensity level. As load increased, minimum humeral flexion increased by 11.35° (11.36°) and 12.07° (12.03°) for the right and left arms, respectively, while mean and maximum humeral flexion angles remained consistent across all levels (Figure 14).

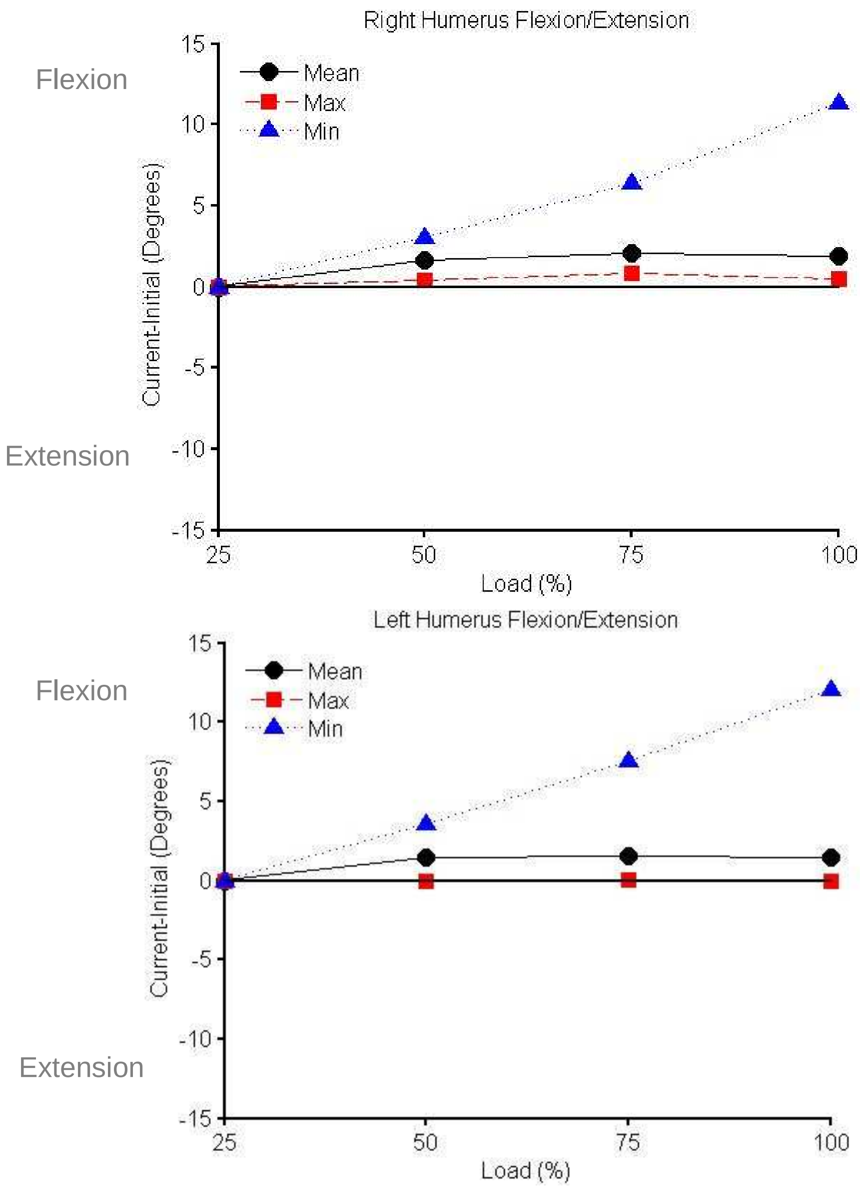


Figure 14: Humeral flexion angle of the right (top) and left (bottom) arm for the waist to overhead lift. Only minimum flexion angle changed significantly with load.

Flexion/extension and ulnar/radial deviation angle changed significantly for both wrists during the waist to overhead lift. Mean, maximum, and minimum wrist flexion/extension angle all decreased for the right wrist, while mean and minimum angle decreased significantly for the left wrist (Figure 15). In terms of anatomical angles, the decreasing angles reflect an increase in wrist extension. Regarding ulnar/deviation angle, minimum angle increased for both wrists by 4.72° (16.88°) for the right and 5.96° (15.24°) for the left from the 25% load to the 100% load (Figure 16).

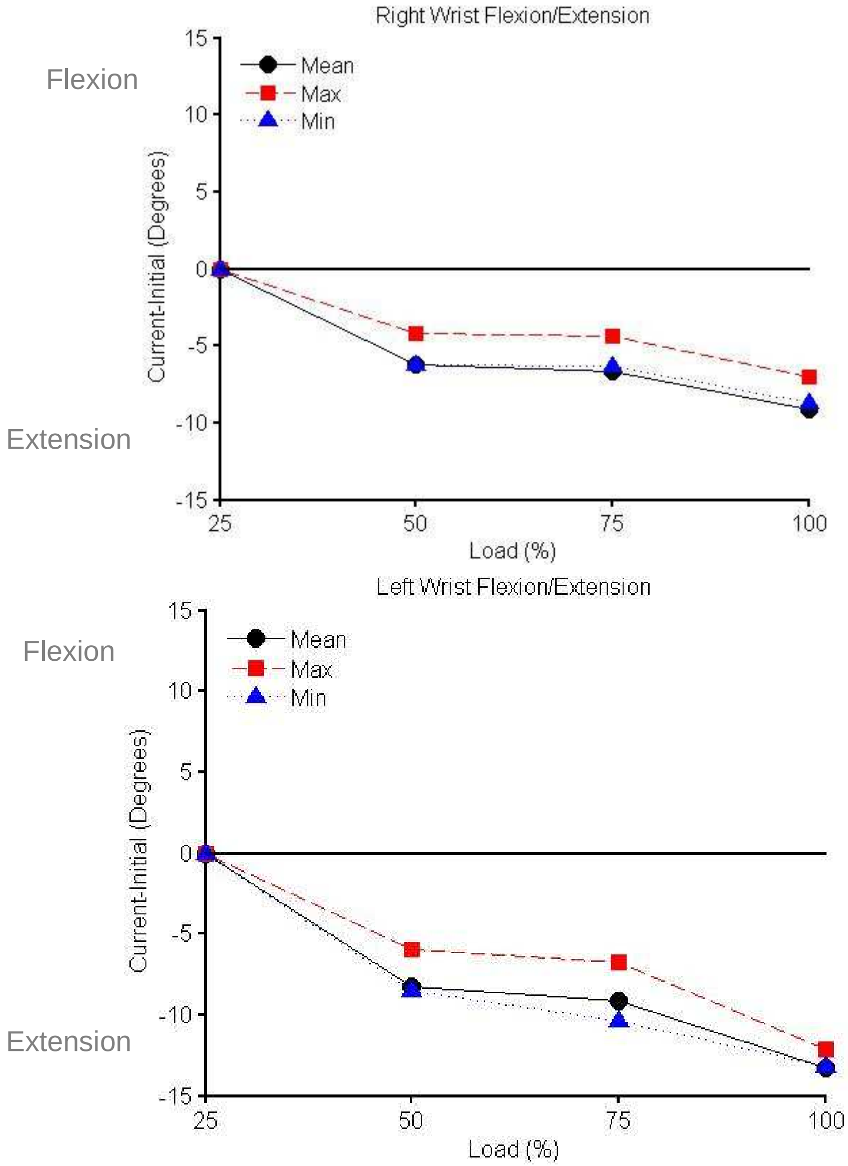


Figure 15: Wrist flexion/extension angle for the right (top) and left (bottom) arm for the waist to overhead lift. The decreasing angle reflects an increase in wrist extension.

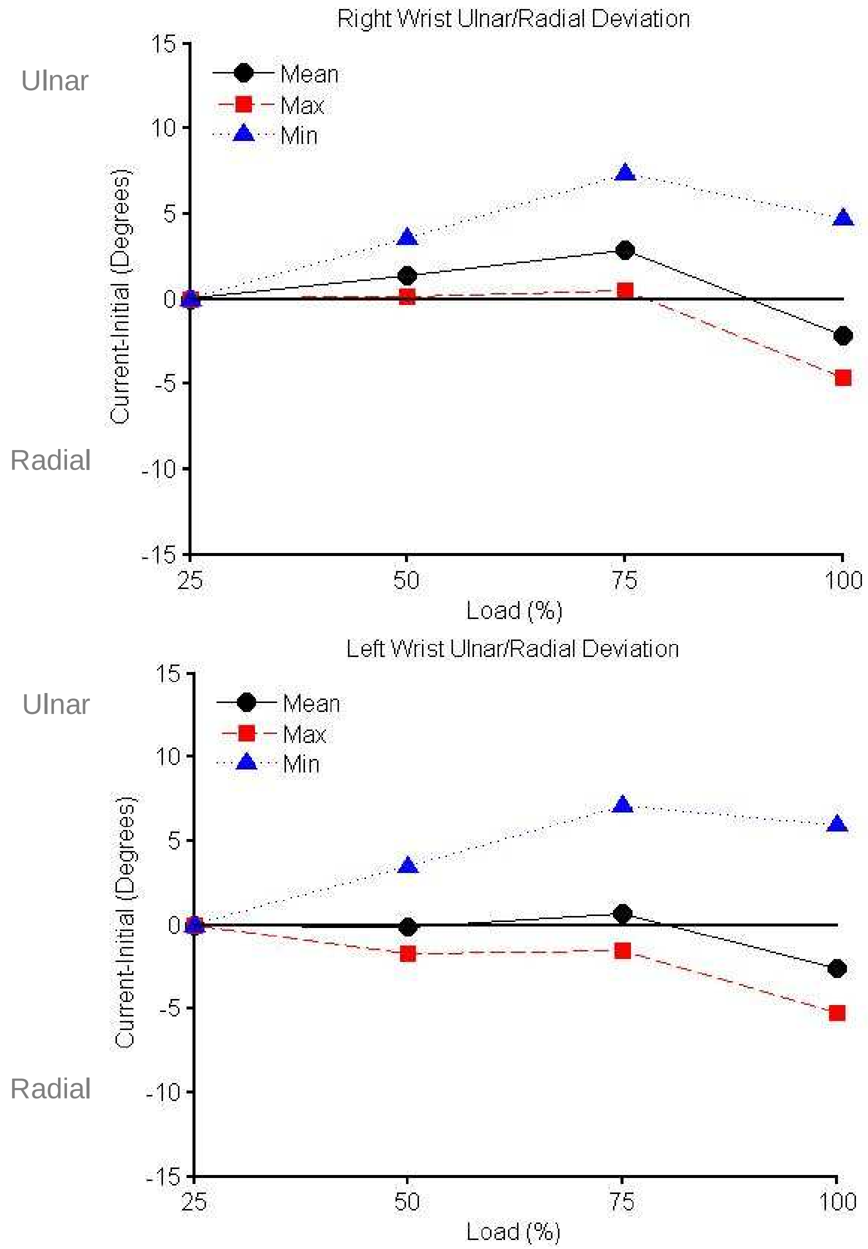


Figure 16: Wrist ulnar/radial deviation angle for the right (top) and left (bottom) arm for the waist to overhead lift. Only minimum angle increased significantly.

During the prolonged overhead work task, torso extension mean and maximum angles increased significantly with time, with a maximum change of 6.9° (3.96°) and 11.79° (4.39°), respectively (Figure 17). Minimum torso angle also increased, but with a magnitude less than 5°.

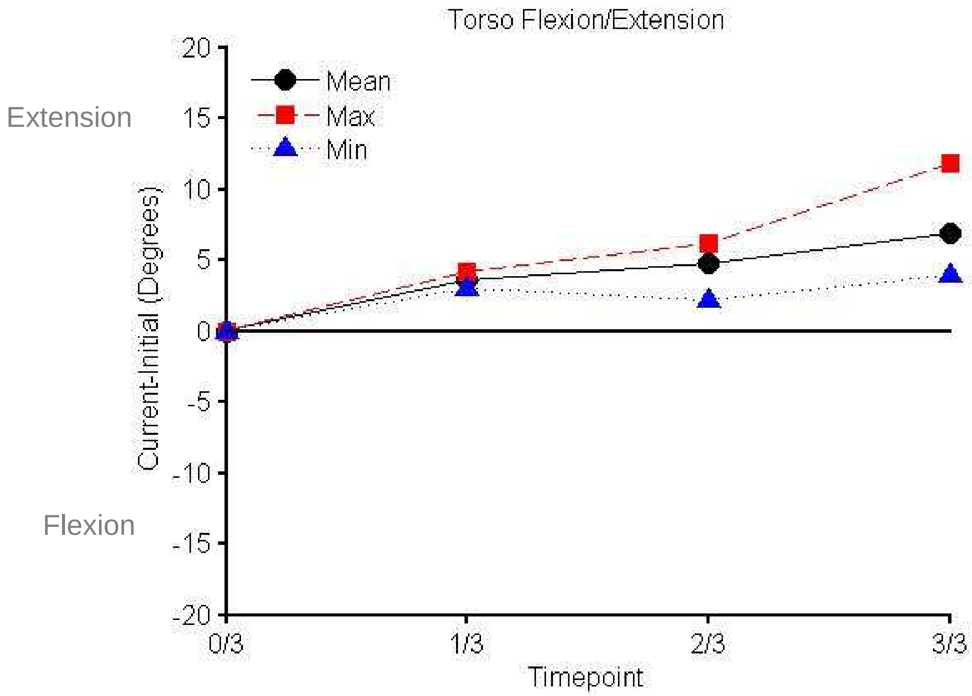


Figure 17: Torso flexion/extension angle change from initial during the overhead work task. The increasing angles indicates and the increase of torso extension with time.

Mean, maximum and minimum humeral flexion (Figure 18) and humeral axial rotation (Figure 19) angles for the right side changed significantly as participants reached their maximum capacity. Axial rotation had the largest change, increasing by 13.58° (13.90°), 10.64° (25.43°), and 15.04° (23.07°) for the mean, maximum and minimum angles, respectively. The increasing axial rotation reflects a decrease in external rotation.

All three thoracohumeral angles of the left arm also changed significantly with time. Humeral abduction decreased in all parameters (Figure 20), as did humeral flexion mean and minimum (Figure 18). Left humeral mean and minimum axial rotation increased significantly by

14.26° (14.37°) and 18.4° (18.01°), demonstrating the same decrease in external rotation as seen in the right arm (Figure 19).

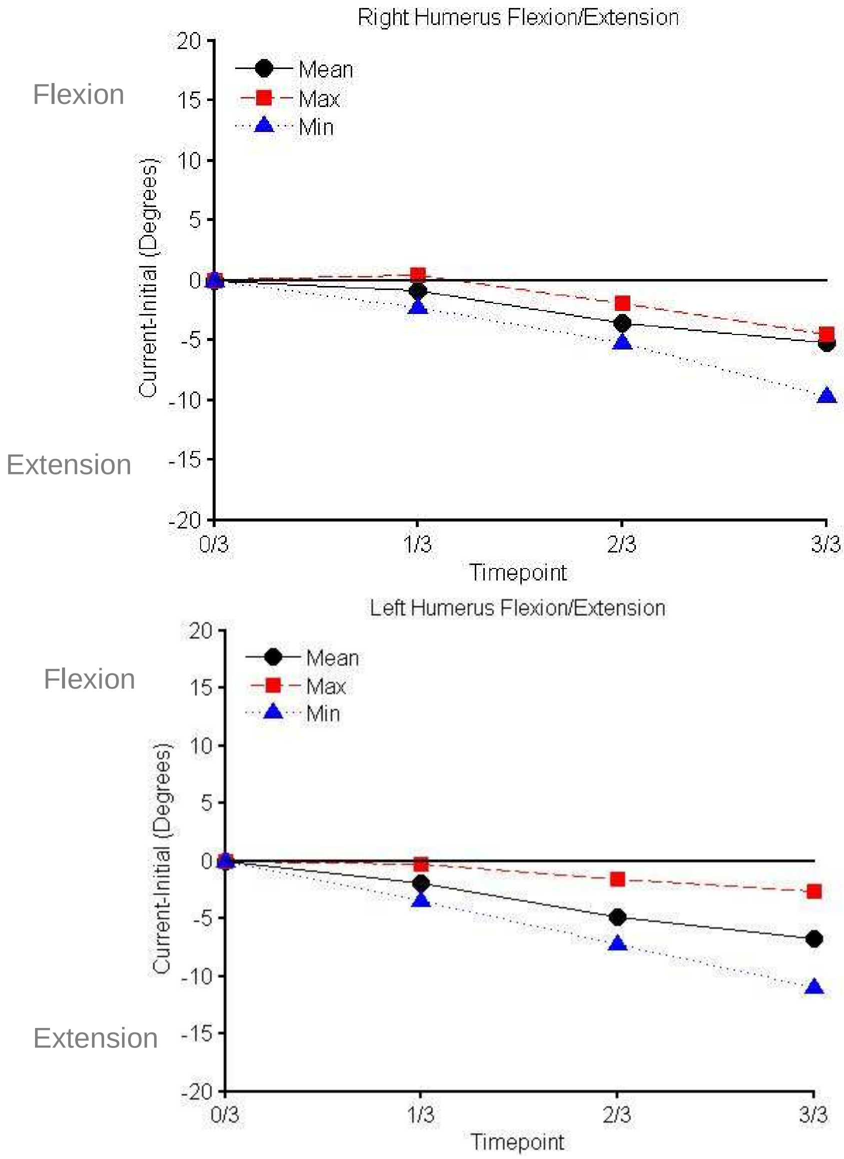


Figure 18: Humeral flexion angle of the right (top) and left (bottom) arm for the overhead work task. All measures decreased with time.

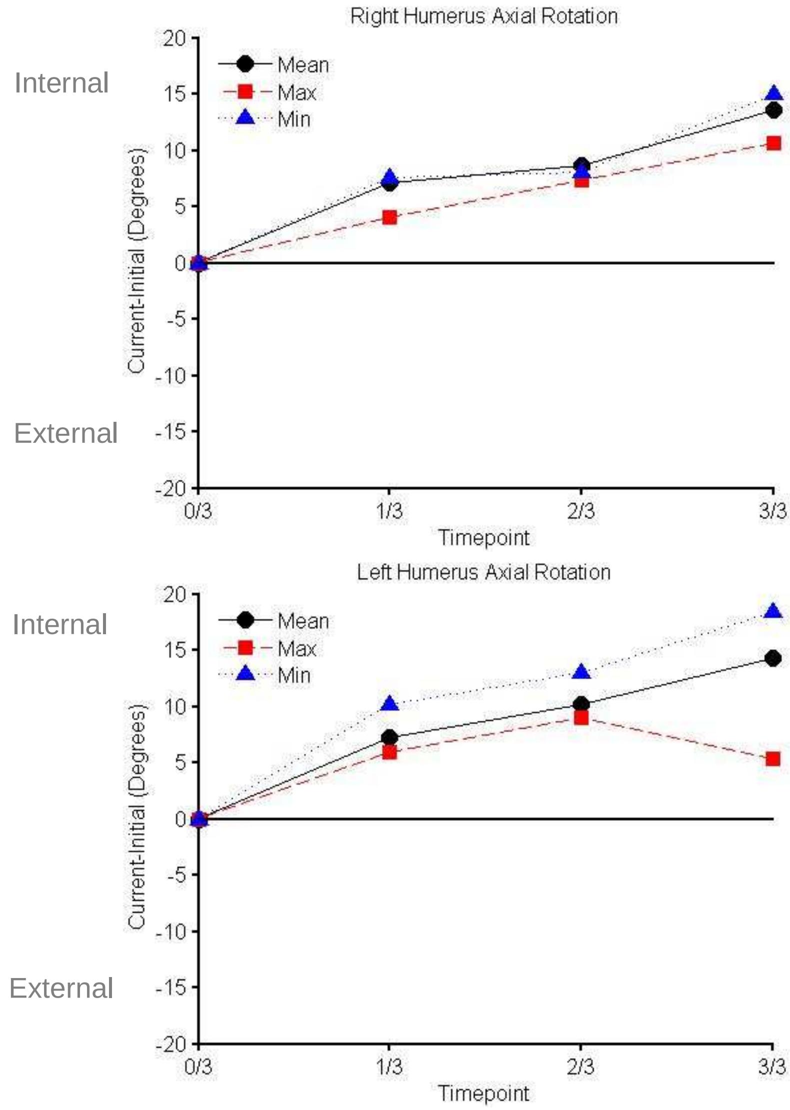


Figure 19: Humeral axial angle of the right (top) and left (bottom) arm for the overhead work task. The increasing angles reflect an increase internal rotation.

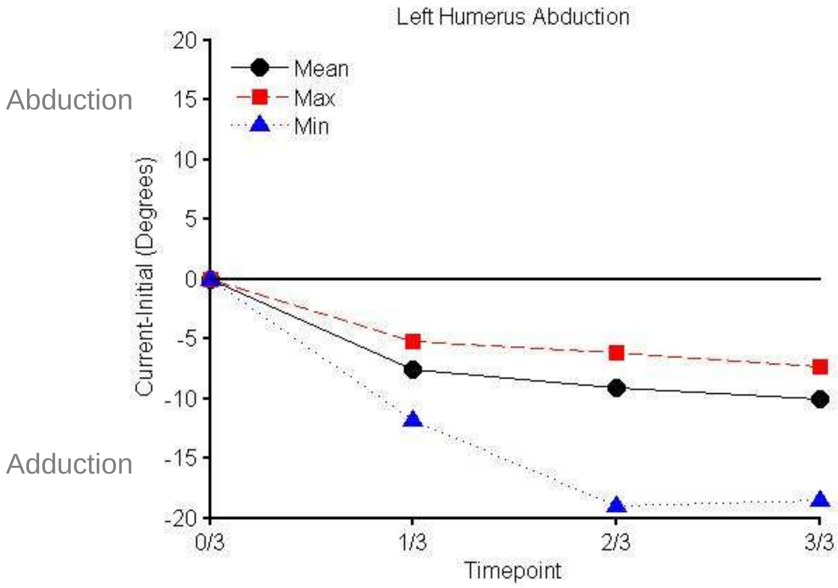


Figure 20: Humeral abduction angle of the left arm for the overhead work task. The decreasing angle reflects a decrease in abduction with time.

During the overhead work task, right elbow flexion increased with intensity by 9.08° (8.83°), 9.54° (11.93°), and 6.38° (16.07°) for mean, maximum, and minimum, respectively (Figure 21). Maximum pronation changed significantly also, decreasing from the initial angle for the first two time points and increasing by 5.24° (16.41°) from initial for the final 30 seconds (Figure 22). Mean, maximum, and minimum values of left elbow flexion also increased with time, with increases of 10.37° (10.45°), 13.19° (15.52°), and 6.28° (16.94°), respectively.

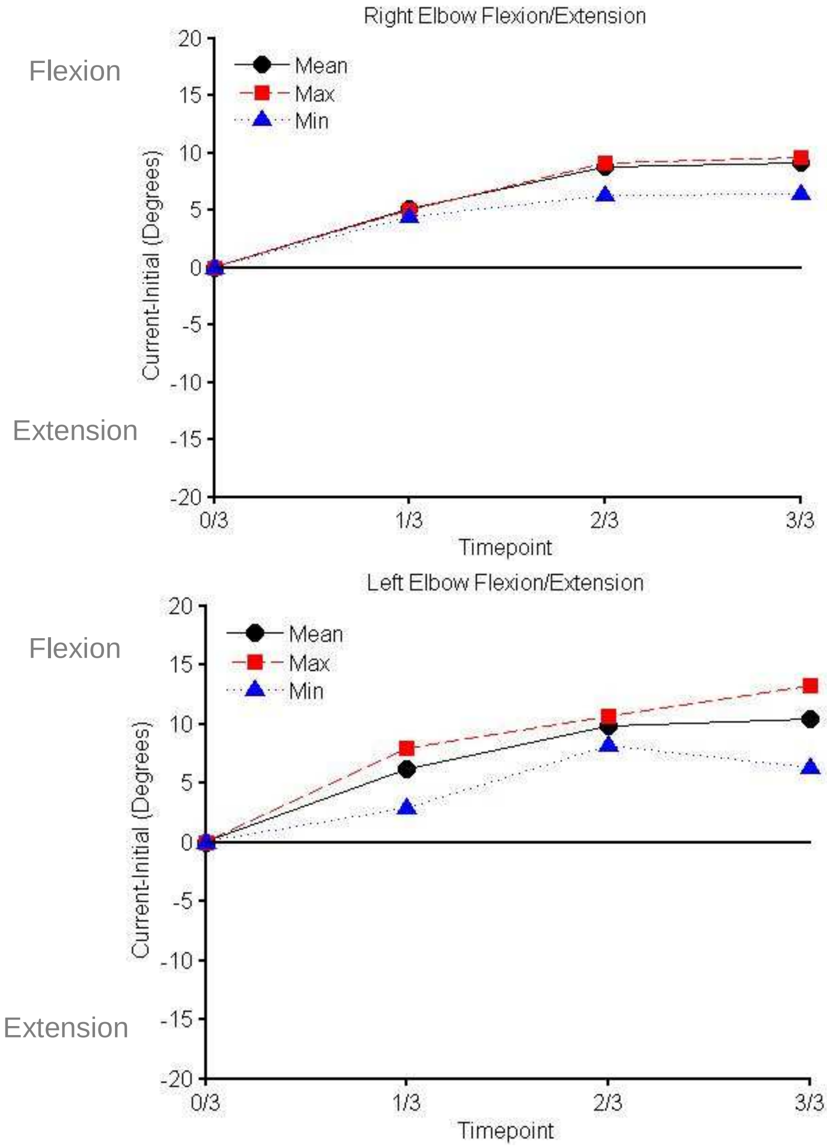


Figure 21: Elbow flexion/extension angle of the right (top) and left (bottom) arm for the overhead work task. Increasing angles reflect an increase in elbow flexion.

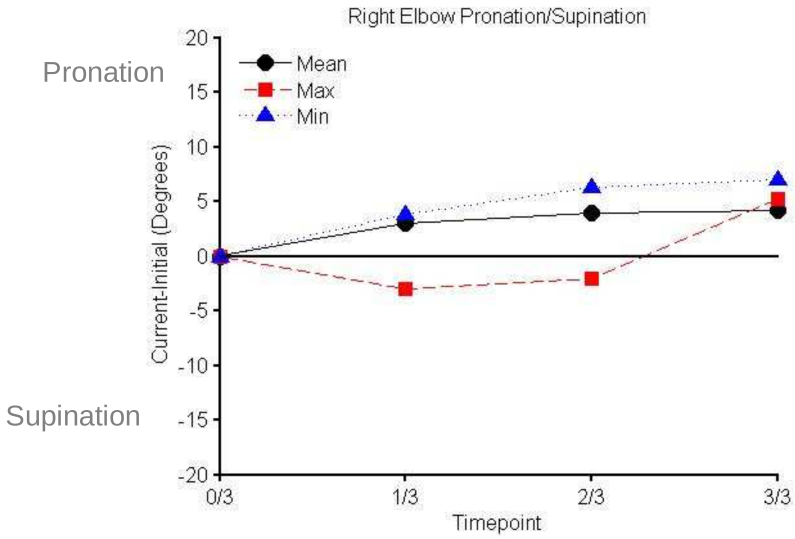


Figure 22: Pronation angle of the right arm for the overhead work task. Maximum pronation had a parabolic change across the time points.

Similarly to the changes in the lift task, the flexion/extension angle of both wrists changed with time (Figure 23). Mean right wrist angle decreased by 11.17° (11.41°), maximum angle decreased by 13.31° (16.01°), and minimum angle decreased by 10.02° (11.76°). The same parameters of the left wrist also decreased by 11.44° (10.51°), 11.79° (21.59°), and 12.01° (12.26°), respectively. Due to the direction of the rotations, these decreases reflect an increase in wrist extension for both wrists.

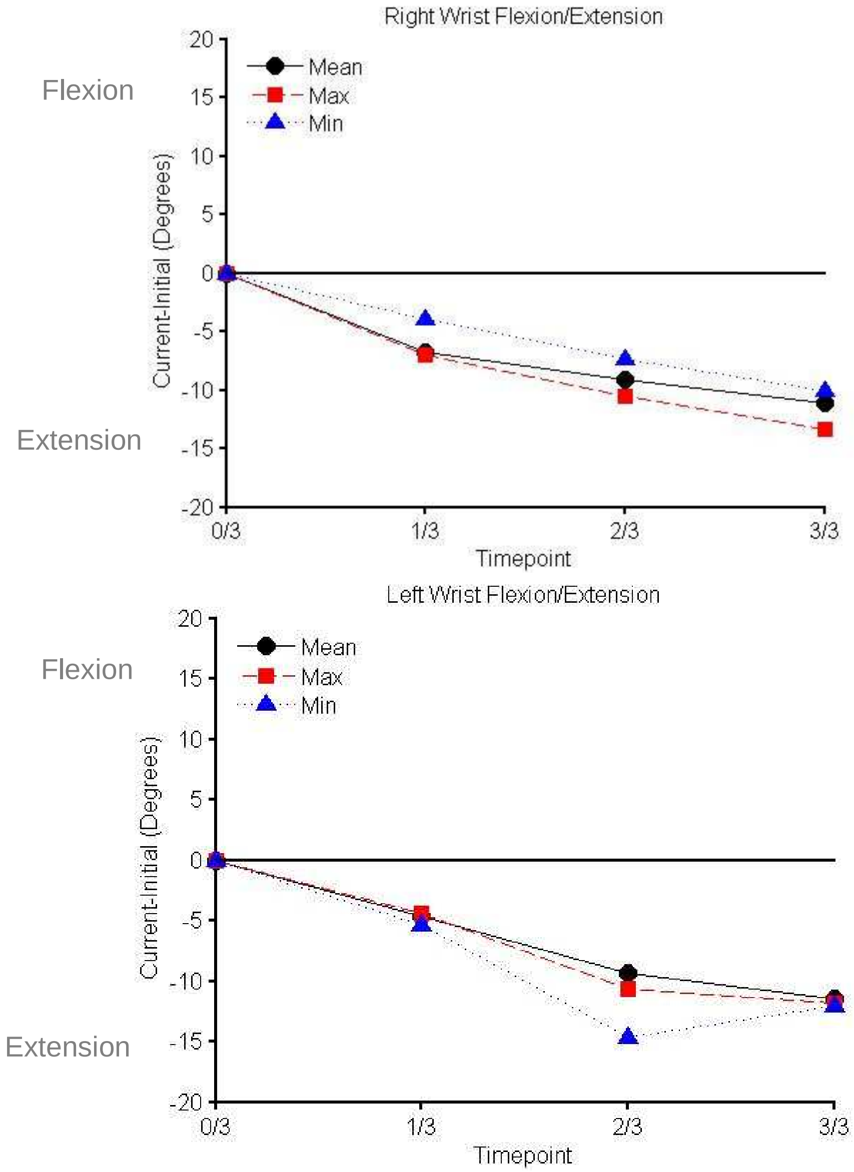


Figure 23: Wrist flexion/extension angle of the right (top) and left (bottom) arm for the overhead work task. The decreasing angle reflects an increase in wrist extension.

4.3 Velocity

4.3.1 Sex

Segment velocity is presented as the aggregate of males and females. The number of comparisons that had a significant result was only 3.4% of the total number of tests and as such there is a high likelihood of false positives.

4.3.2 Intensity

Main effects of intensity (p<.05) existed for velocity of all segments for both overhead tasks.

Both mean (Figure 24) and maximum (Figure 25) resultant velocities were affected by increases in load during the waist-to-overhead lift. As load increased, torso velocity increased by approximately 50% from the 25% load to the 100% load for mean and maximum measures. Conversely, velocity decreased with intensity for all segments of the arm. Mean velocity decreased for the right and left humeri by 9% while maximum velocity decreased by 8% and 5%, respectively. Forearm velocity decreased by an average of 16% for the mean and 14% for the maximum values. Mean velocity of the right and left hand decreased by 18% and 20%, while maximum velocity decreased by 11% and 16%, respectively.

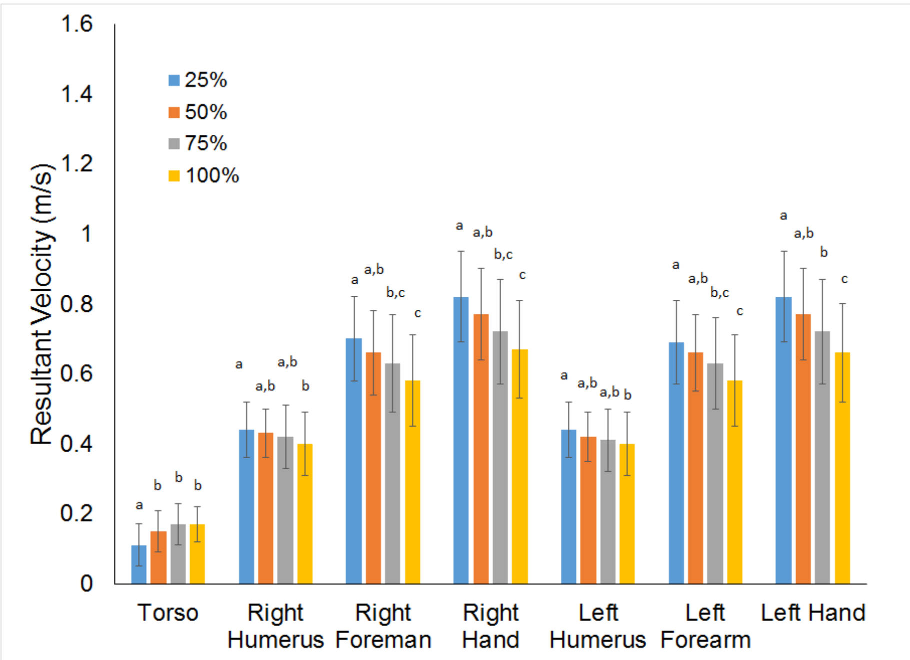


Figure 24: Mean resultant velocity for the torso and all segments of the upper limbs for the 4 levels for the waist to overhead lift task. Levels connected by the same letter are not significantly different.

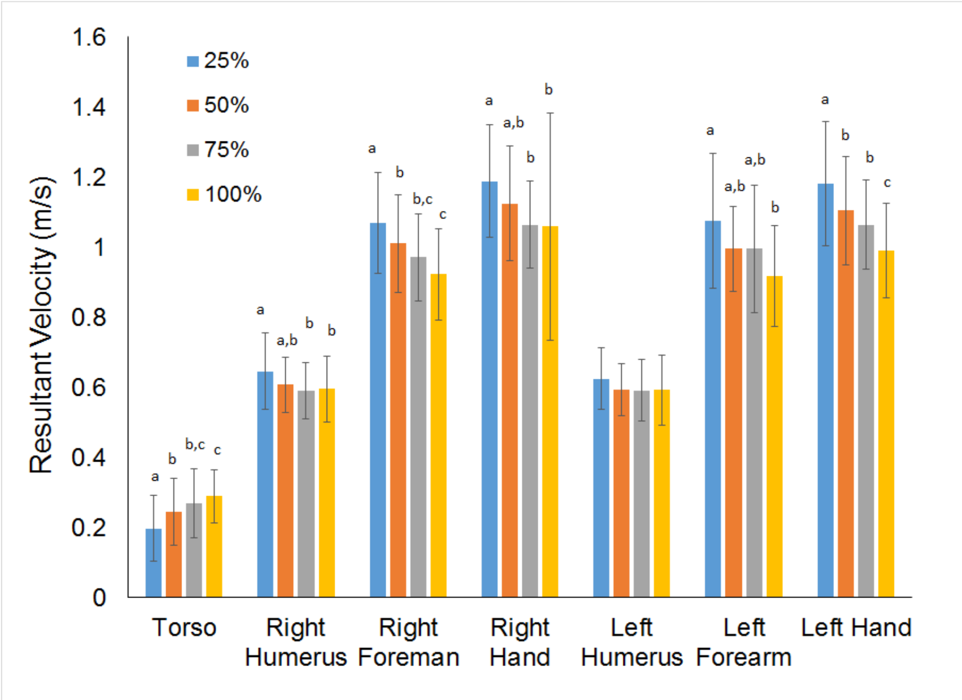


Figure 25: Maximum resultant velocity for the torso and all segments of the upper limbs for the 4 levels for the waist to overhead lift task. Levels connected by the same letter are not significantly different.

In the overhead work task, mean resultant velocity increased for all segments (Figure 26). Torso mean velocity increased significantly by 82% from the first 30 seconds to the last 30 seconds. Mean velocity of the right humerus, forearm and hand all increased as well, by 38%, 37%, and 23%, respectively. For the left side, mean velocity increased by 62%, 63%, and 46% for the humerus, forearm, and hand. Maximum resultant velocity only changed significantly for the torso during the work task (Figure 27).

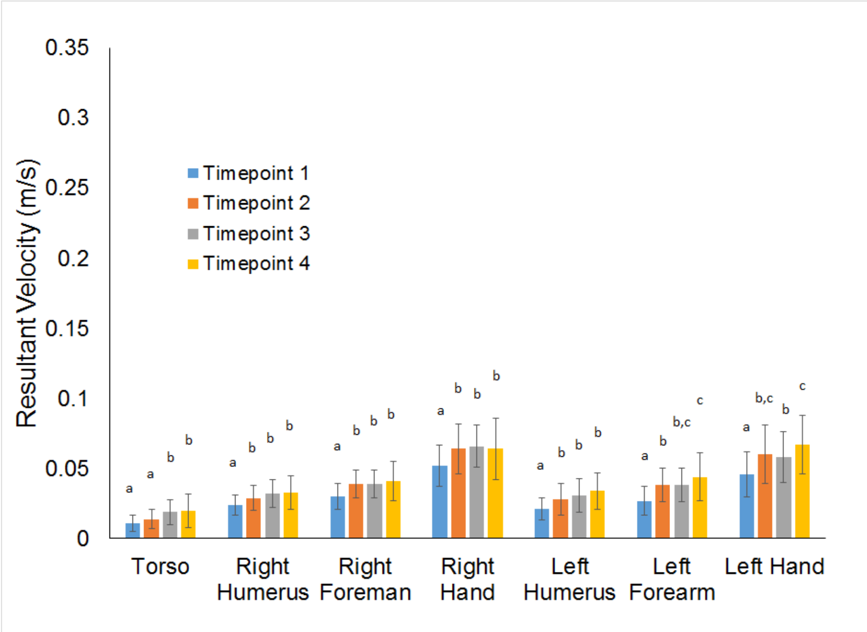


Figure 26: Mean resultant velocity for the torso and all segments of the upper limbs for the 4 levels for the overhead work task. Levels connected by the same letter are not significantly different.

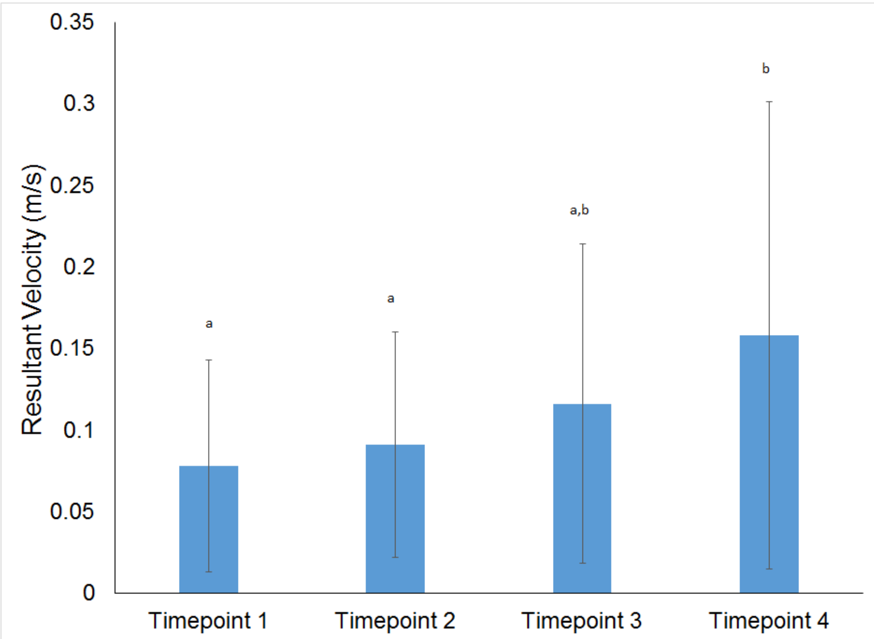


Figure 27: Maximum resultant velocity for the torso for the 4 levels for the overhead work task. Levels connected by the same letter are not significantly different.

4.4 Kinematic Profiles

While the waist-to-overhead lift and the overhead work have increasing levels, the reaching and dexterity tasks required participants to perform at their highest effort level for every trial. As such, it is not only important to understand how the changes caused by increasing intensity in the overhead tasks affect the relative joint angles, but also the kinematics of those tasks with one level of effort. Joint profiles for all angles of each joint are available in Appendix D, but the characteristic angles for each task will be presented here. Just the profiles of the right arm will be displayed in the results to avoid redundancy.

Kinematic profiles were created by ensemble averaging all participant curves. Of the 3150 curves used to create profiles for each task, 47 curves were not used.

4.4.1 Repetitive Reaching Task:

While the mean torso flexion/extension angle remained relatively constant at an average of 16.05° throughout each cycle and subtask, torso axial rotation varied (Figure 28). Healthy participants used an average absolute range of 40.05° of axial rotation for each subtask, but due to the different directions of movement and use of both hands, the relative range varied.

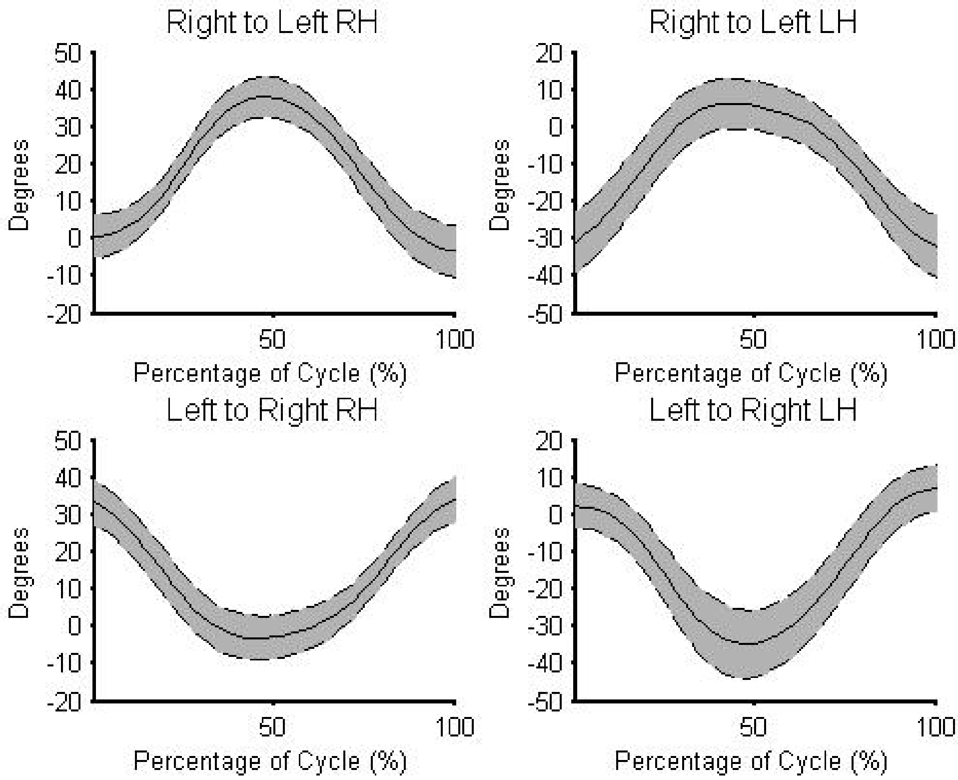


Figure 28: Mean torso +left/-right axial rotation kinematic profiles with +/- one standard deviation during the repetitive reaching subtasks.

The thoracohumeral curves also have characteristic shapes that change with direction. Thoracohumeral abduction and flexion best describe the motion at this joint during this task and they have opposite patterns (Figure 29). When the hand being used is the same as the starting side (i.e. right hand moving right to left), peak abduction, which is an average of 51.22°, occurs at the beginning and end of the cycles while flexion is at a minimum at those time points. Mid cycle, when the hand is at the second bowl, flexion peaks with an average of 70.65° and abduction is at its lowest. When the hand being used is different from the starting side (i.e. right hand moving left to right), peak flexion occurs at the beginning and end of the cycle and is lowest in the middle, while abduction has the opposite pattern.

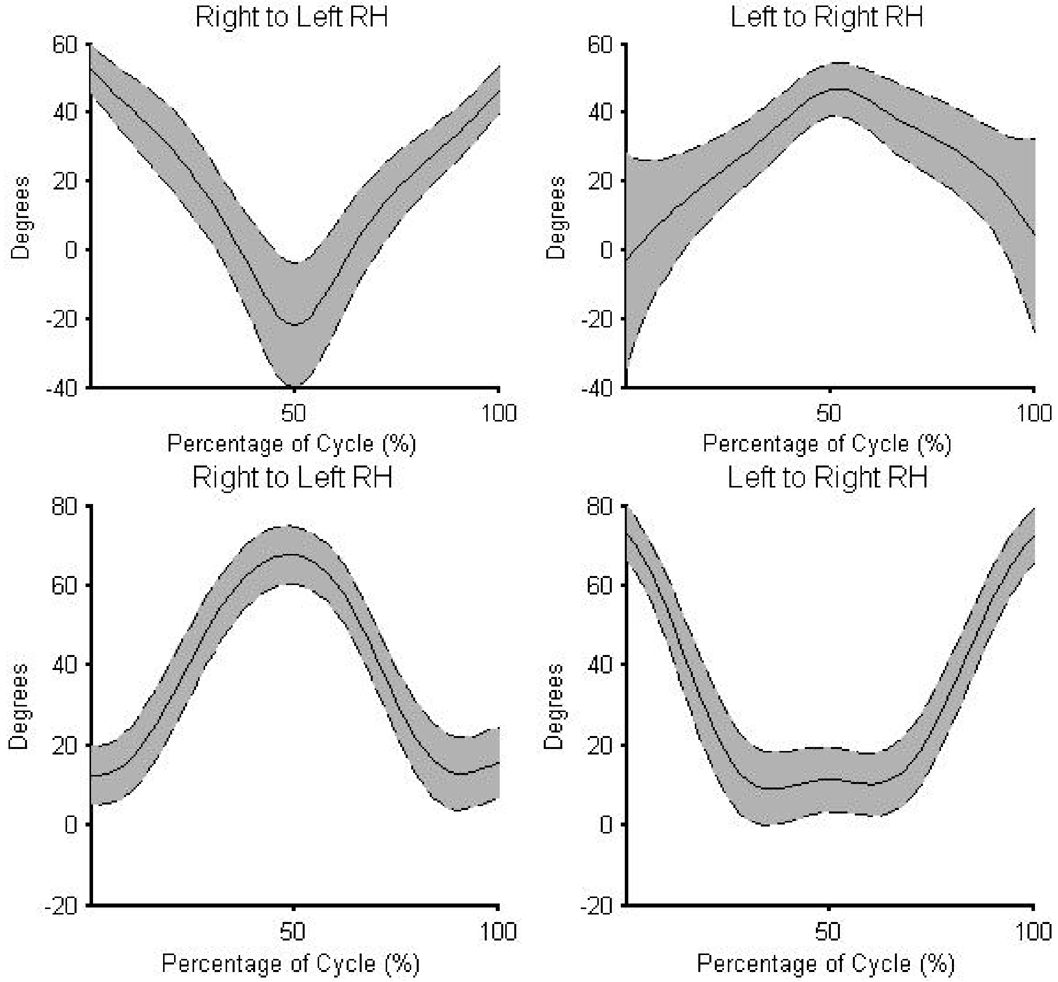


Figure 29: Mean humeral abduction (top) and flexion (bottom) angles of the right arm with +/- one standard deviation during the repetitive reaching task. In the same direction/hand sub task (right) abduction peaks during marble pick up and flexion peaks during marble drop off but during the opposite direction/hand the pattern is reverse.

Regardless of hand used or direction of movement, elbow angle had a consistent pattern during the repetitive reaching task. The elbow is extended at the beginning of the cycle during marble pick up, bends to an average flexed position of 96.36° for the right arm and 105.93° for the left arm during travel between the bowls, and then reaches a maximum extension angle of 39.05° and 51.71° of flexion mid cycle, during marble drop off, for the right and left arms, respectively (Figure 30). This pattern is repeated on the way back to the starting position to complete the cycle. Pronation angle remains relatively steady throughout each cycle, at average around 129.11° for both hands (Figure 31).

In all subtasks of the RRT, the wrist had no obvious pattern of movement and the average flexion/extension angle was approximately neutral, while both wrists maintained a slightly ulnar deviation position, with right wrist deviation an average of 7.46° of deviation and the left wrist an average of 24.92°.

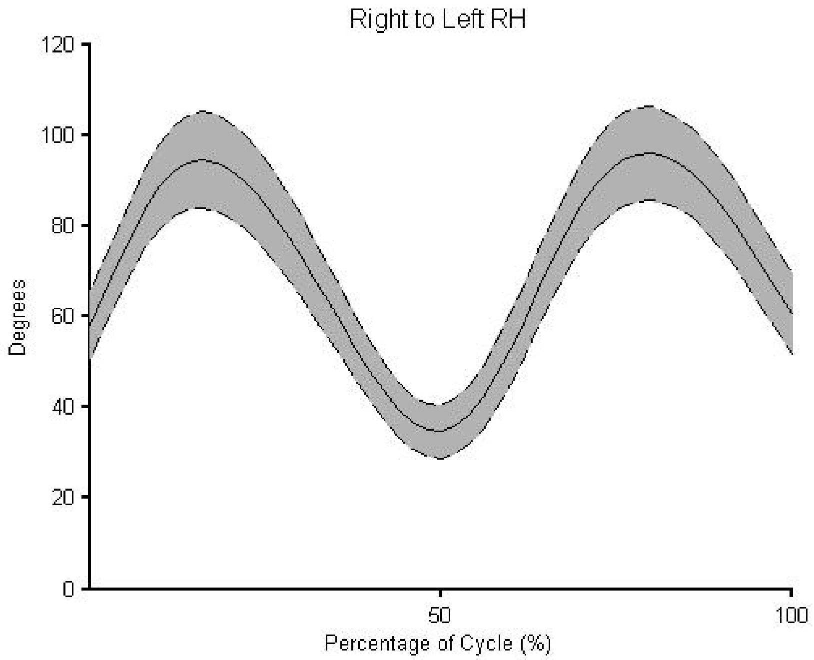


Figure 30: Mean elbow flexion angle of the right arm with +/- one standard deviation during the repetitive reaching task. The pattern was the same for all subtasks.

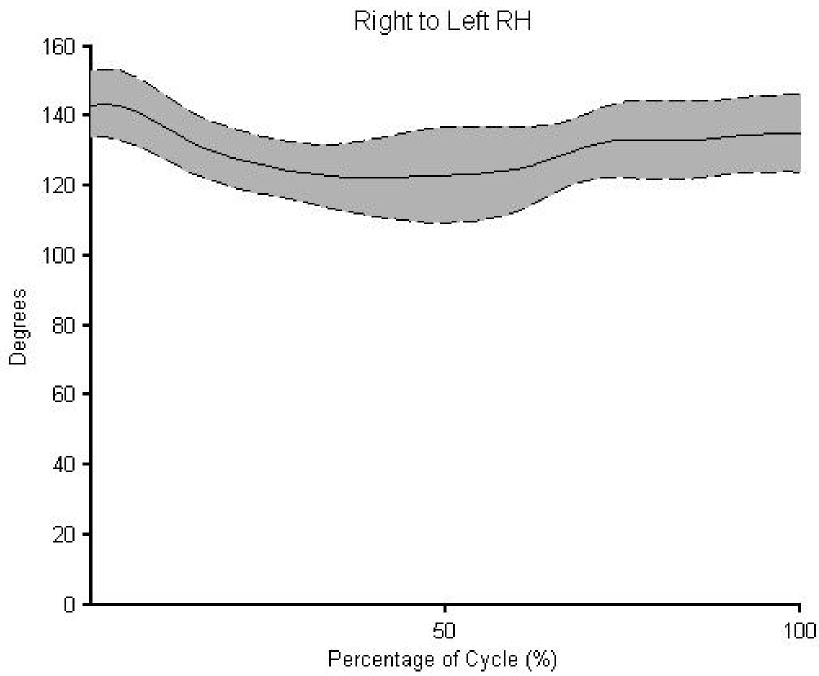


Figure 31: Mean pronation angle of the right arm with +/- one standard deviation during the repetitive reaching task. The angle remained relatively consistent throughout each cycle and subtask.

4.4.2 Fingertip Dexterity (Purdue Pegboard):

The fingertip dexterity task is largely a postural task with minimal movement. For each subtask participants maintained an average 15.49° of torso flexion (Figure 32). Torso axial rotation posture varied with subtask, however. The torso was rotated 11.59° to the left during the right hand task and 8.67° to the right during the left hand task, while during the tasks requiring both hands the participants axial rotation posture was neutral (Figure 33).

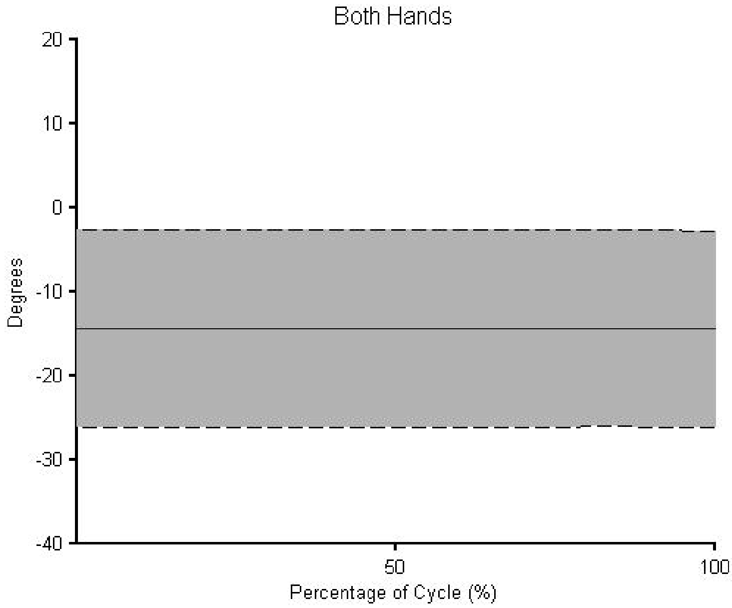


Figure 32: Mean torso flexion/extension angle with +/- one standard deviation during the fingertip dexterity task. The angle remained relatively consistent throughout each cycle and subtask.

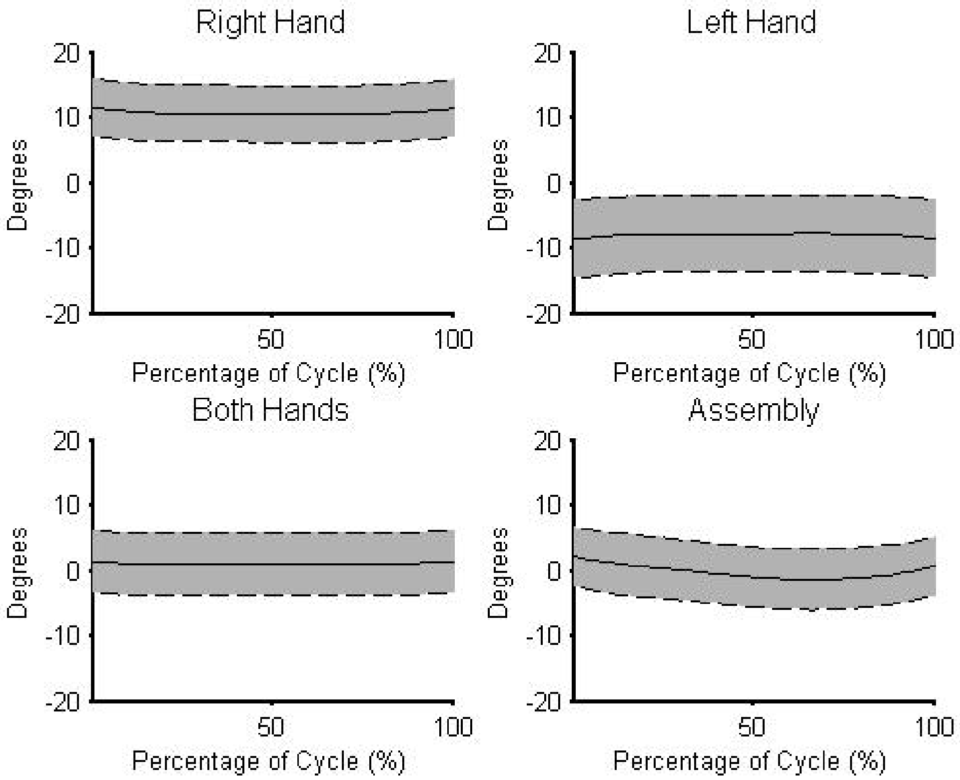


Figure 33: Mean torso axial rotation angle with +/- one standard deviation during the fingertip dexterity task. During the right hand (top right) and left hand (top left) subtasks, the torso was slightly rotated to the working side while in the both hands (bottom right) and the assembly (bottom left) tasks, axial rotation was approximately neutral.

For all subtasks of the fingertip dexterity task, there were only small movements of the arm joints. Thoracohumeral abduction remained relatively constant for each cycle, but decreased from an average of 41.46° in the single hand subtasks to 28.57° in the both hands subtask and 26.11° assembly during the assembly subtask. Both humeral flexion and axial rotation had a similar but opposite patterns (Figure 34). Flexion angle was highest when reaching for a pin and then reached a lower plateau while placing the pin, while axial rotation angle had a slight increase of internal rotation during pin placement (Figure 35). The range of both angles was 15° or less for all subtasks.

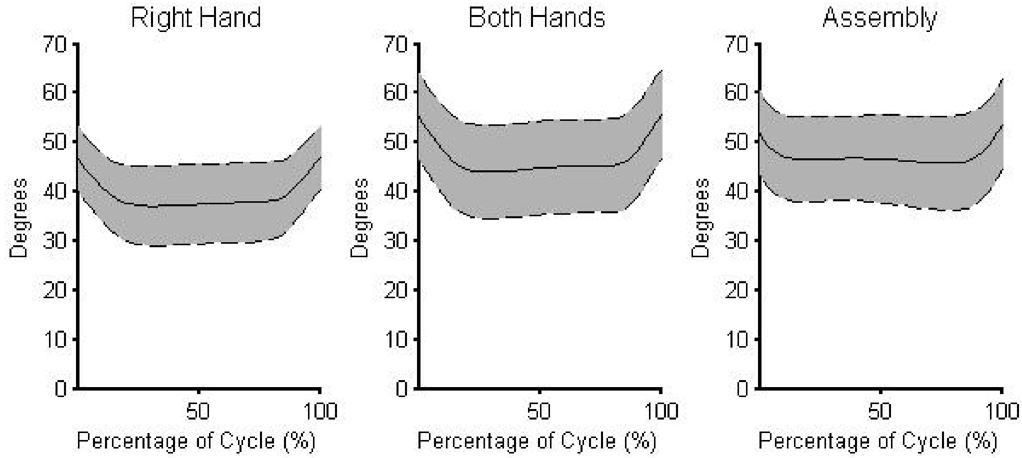


Figure 34: Mean humeral flexion angle of the right arm with +/- one standard deviation during single hand (far left), both hands (middle), and assembly (far right) subtasks of the fingertip dexterity task. Flexion decreases slightly during pin placement.

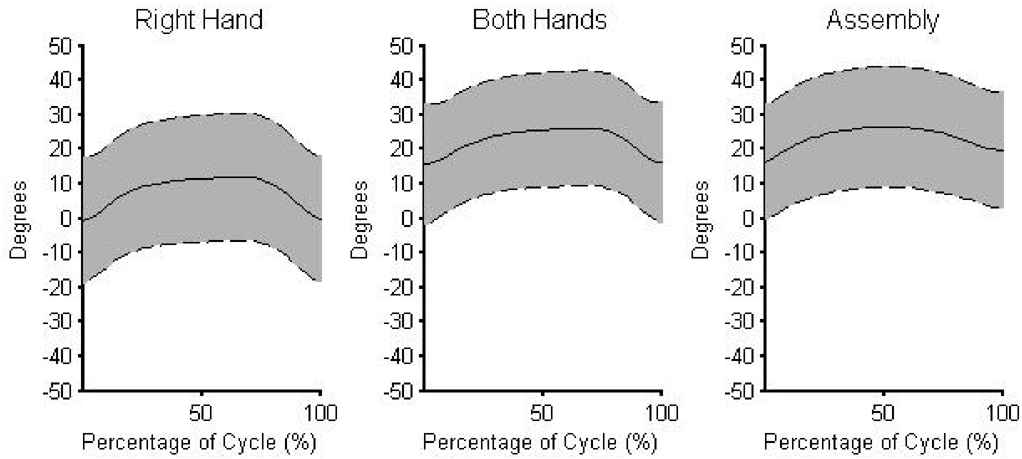


Figure 35: Mean humeral axial rotation angle of the right arm with +/- one standard deviation during single hand (far left), both hands (middle), and assembly (far right) subtasks of the fingertip dexterity task. Internal rotation increases during pin placement for all subtasks.

The elbow also used a small flexion range of motion; approximately 20° (Figure 36). At the beginning and end of each cycle, while the participant is reaching for the pin, elbow flexion is at the lowest, an average of 61.19° for the right arm and 69.50° for the left. While the pin is being placed, elbow flexion increased to approximately 77.98° and 86.63°. Elbow pronation remained around a mean of 127.61° for both hands in all trials.

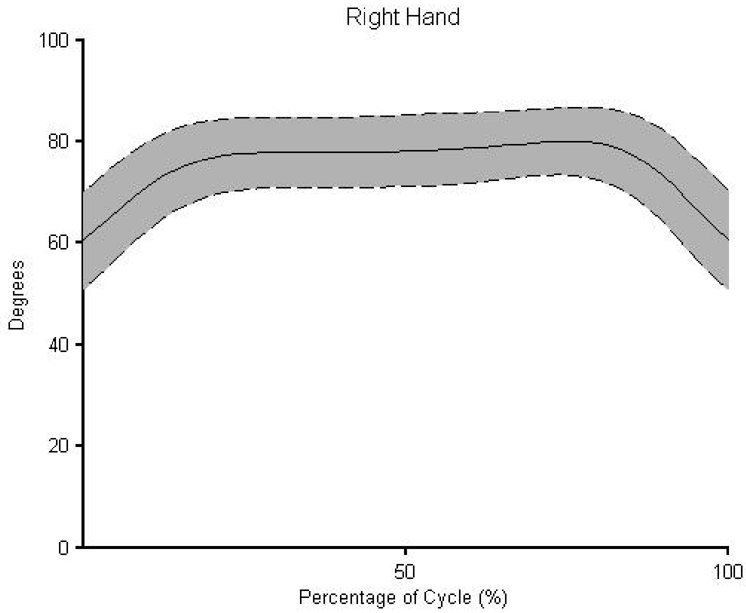


Figure 36: Mean elbow flexion of the right arm with +/- one standard deviation during the single hand (right hand) fingertip dexterity subtask. All subtasks had a similar pattern.

Similar to the repetitive reaching task, both wrists remained, on average, in a neutral position for both flexion/extension and ulnar/radial deviation angles, with the exception of the left wrist ulnar deviation angle, which was a mean of 15.62° for all subtasks.

4.4.3 Hand and Forearm Dexterity (Minnesota Manual Dexterity)

There are two subtasks of the hand and forearm dexterity and they are presented differently due to the nature of the subtasks. The placing task can be defined in cycles and each trial is split into thirds, while the turning task cannot be defined into cycles and instead the whole trial is analyzed and presented together.

For the placing task, torso flexion/extension and lateral flexion remained constant for each cycle at an average of 16.4° of flexion and 3.4° of left lateral flexion. Conversely, average left axial rotation increased from the first third (2.96°) to the last third (16.89°) of each trial (Figure 37). It is important to note that these curves reflect only the right handed participants (28/30); for left handed participants, axial rotation would be to the right, and would decrease from the first third to the last third.

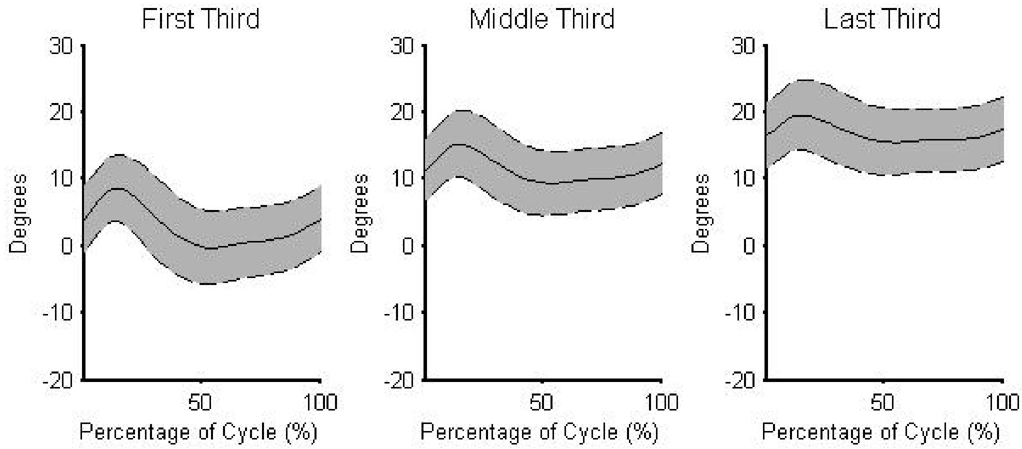


Figure 37: Mean axial rotation of the torso of each third of the hand and forearm dexterity placing task for right handed participants. Axial rotation to the left peaks slightly during block pick up and increases the hand moves from right to left.

All three degrees of the thoracohumeral angle changed from the first to last third. Mean abduction angle was similar for the entire task, but the range was largest in the first third (Figure 38). Mean flexion angle increased from 17.7° to 46.16° as the participants moved across the board (Figure 39). Finally, mean axial rotation changed from 2.55° of external rotation in the first third, to 15.82° and 16.72° of internal rotation in the middle and last third, respectively. The first and last third curves for all angles would be switched for left handed participants.

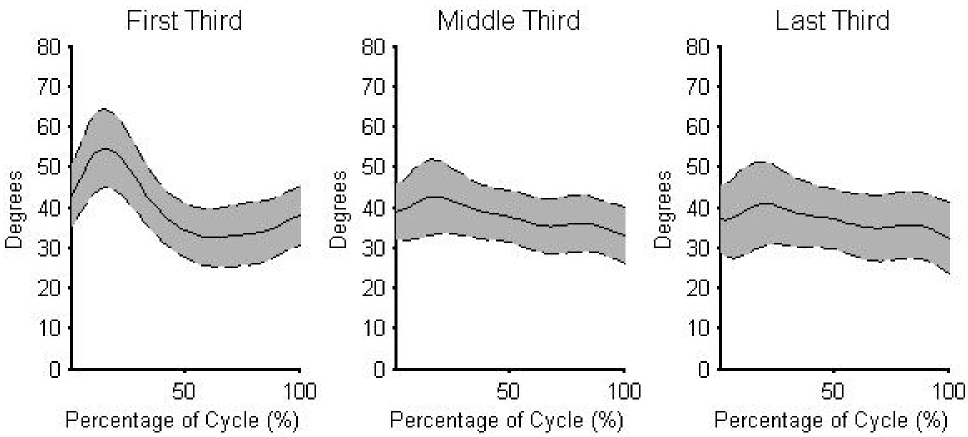


Figure 38: Mean humeral abduction of the right arm with +/- one standard deviation during the hand and forearm dexterity placing task. Abduction peaks during block pick up in the first third (far left) of the task but remains relatively constant during the middle third (middle) and last third (far right).

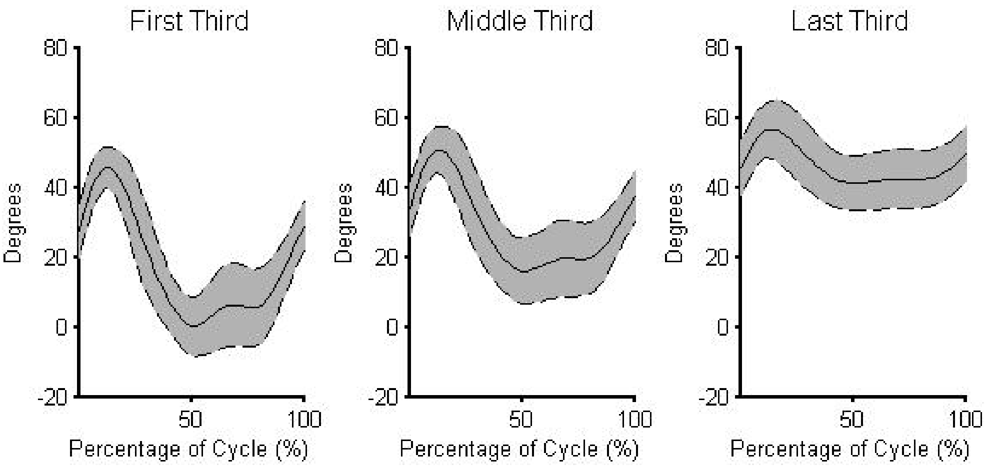


Figure 39: Mean humeral flexion angle of the right arm with +/- one standard deviation during the hand and forearm dexterity placing task. Maximum flexion angle peaks during block pick up in each cycle and minimum flexion occurs during block placement. Minimum flexion angle is lowest in the first third (far left) and increases for the middle third (middle) and the last third (far right).

Elbow flexion/extension angle had a similar pattern for the entire task. At the beginning of the task, when the arm crossed the top edge of the board, elbow flexion was approximately 90°. It decreased to minimum flexion of 45.70° as the block was picked up and then gradually increased during block placement (Figure 40). Pronation angle remained at a relatively constant 135°.

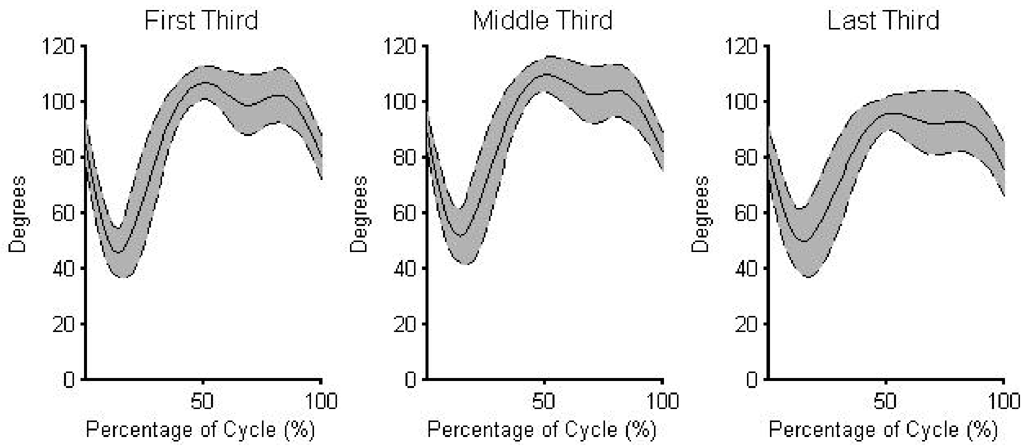


Figure 40: Mean elbow flexion angle of the right arm with +/- one standard deviation during the hand and forearm dexterity placing task. The pattern remains the same for all cycles.

Both wrist flexion/extension angle and ulnar/radial deviation remained close to neutral for the entire placing task.

The second task in the hand and forearm dexterity task is a turning task. The profiles represent the entire task which involves the participant manipulating blocks moving horizontally from right to left and left to right. Torso flexion remained around an average of 19.83°, lateral flexion was approximately neutral while a larger range of motion of axial rotation was used; an average of 22.05° of left rotation to 19.34° of right rotation (Figure 41).

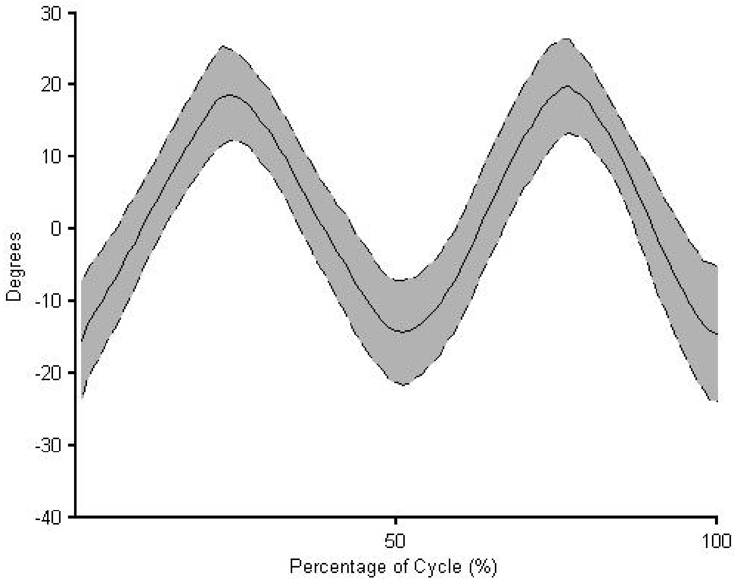


Figure 41: Mean torso axial rotation with +/- one standard deviation during the hand and forearm turning task. Peaks occur when the hands are at the edges of the board.

Humeral abduction ranged from an average of 1.82° to 38.06° during the turning task, with peaks occurring when the hands were at the same side of the board as the arm (i.e. right arm abduction is highest when hands are working at the right edge of the board). Mean flexion angle decreased from 40.47° at the beginning of the task to 18.60° at the end. Finally, humeral internal rotation varied from an average of approximately 20° when the hands are on the same side of the board to an average of approximately 45° when the hands are at the opposite of the board (Figure 42).

Average elbow flexion angle was a relatively straight line and increased from start to finish, from approximately 75° at the start to 100° at the finish.

Similar to the elbow, wrist angles had a small amount of motion. Both wrists had an average angle of 9.76° of extension, while the right wrist ulnar deviation angle was 5.90° and the left wrist around 26.43°.

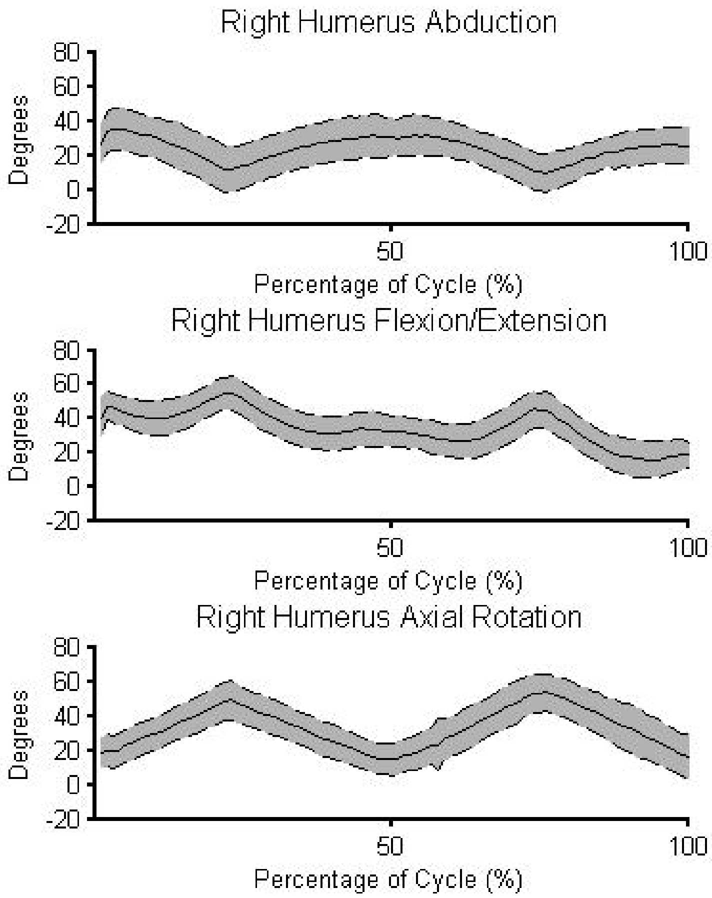


Figure 42: Mean humeral abduction (top), flexion (middle), and axial rotation (bottom) of the right arm with +/- one standard deviation during the hand and forearm turning task. Abduction angle was at a minimum, flexion peaked slightly, and internal rotation peaked when hands were are the far side of the board from the arm (i.e. left side of the board for the right arm). The opposite pattern occurred when hands were at the same side of the board (i.e. right side of the board for the right arm).

4.4.4 Waist to Overhead Lift

During all 4 sets of the lift, both torso lateral flexion and axial rotation remained approximately neutral but torso flexion/extension angle had a larger range of motion and notable changes with intensity (Figure 43).

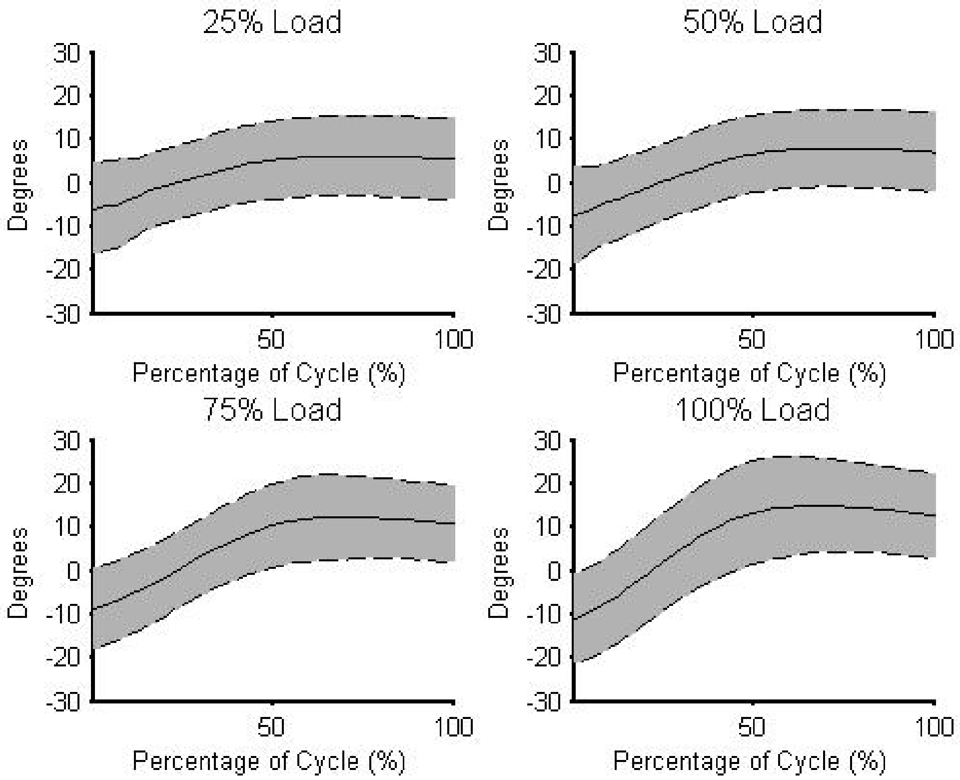


Figure 43: Mean torso flexion/extension angle with +/- one standard deviation in all sets of the waist to overhead lift. Torso flexion is negative and extension is positive. Both maximum flexion and maximum extension increase with load.

Participants, on average, started in a flexed position, as shown by the negative values at the beginning of the curve. The minimum values, or the maximum flexion angle, decreased with intensity from -5.95° to -11.17°. Maximum extension angle, the highest point of the graph, increased with intensity from 6.94° to 17.38°.

The only changes in thoracohumeral angles were in humeral flexion angle. Minimum angle increased as load increased from 6.58° in the 25% load to 18.32° in the 100% load (Figure 44).

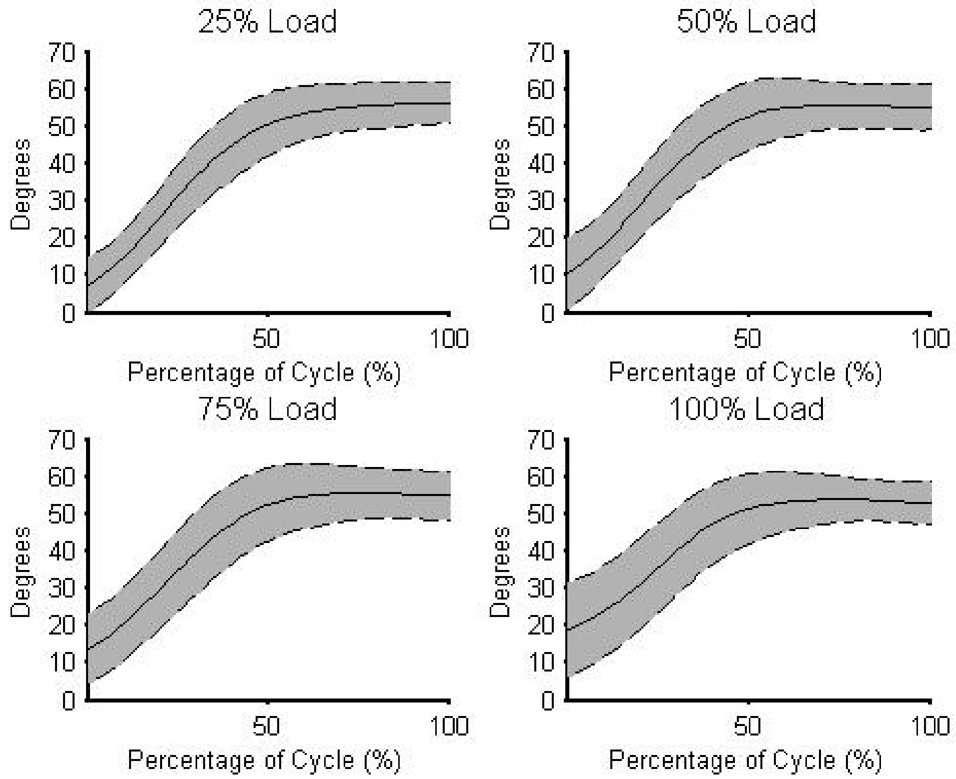


Figure 44: Mean humeral flexion angle of the right arm with +/- one standard deviation during all sets of the waist to overhead lift. Minimum flexion angle, which occurs at the beginning of each cycle, increases with load.

There no significant changes in humeral abduction or axial rotation but large ranges of motion were used for both angles. Participants started each lift with a humeral abduction angle of an average of 21° and axial rotation angle of 13° of internal rotation. Both angles changed as the box was lifted to the height of the shelf to an average of 133° of abduction and 69° of external rotation.

No significant changes from intensity increases were evident in the elbow angles, but both relevant angles spanned a large range of motion in one cycle. Right and left elbow flexion angle spanned from an average of 107° and 120° at the start of the lift to 36° and 44° at the end, respectively (Figure 45). Pronation angle had a similar pattern as flexion angle, beginning at an average of 86° at the start of each lift and decreasing to an average of 37°, for both arms (Figure 46).

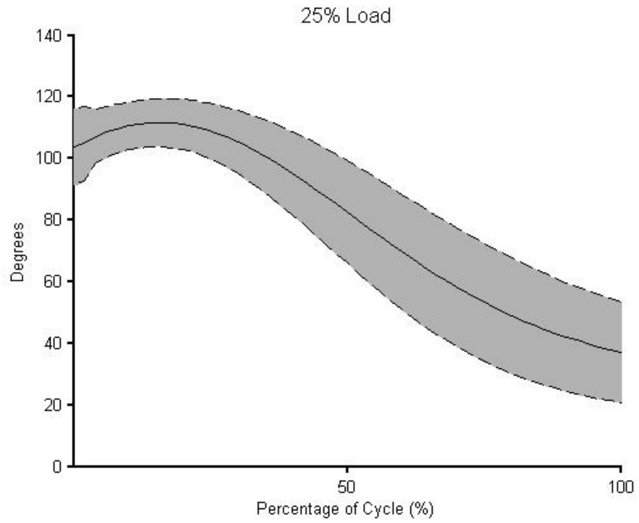


Figure 45: Mean elbow flexion/extension angle with +/- one standard deviation during the 25% load of the waist to overhead lift. The pattern remained the same for all sets of the lift.

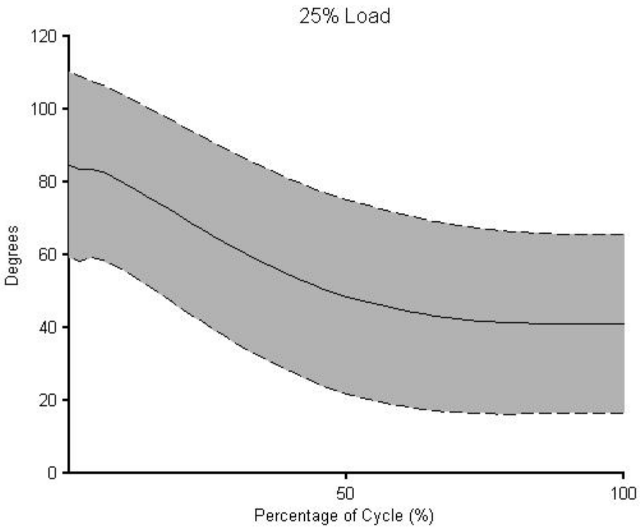


Figure 46: Mean pronation angle with +/- one standard deviation during the 25% load of the waist to overhead lift. The pattern remained the same for all sets of the lift.

Both wrist flexion/extension and ulnar/radial deviation angle changed significantly as load increased. From the 25% load to 100% load, mean wrist extension increased from -4.93° and -6.76° to -14.06° and -20.05° for the right and left wrists, respectively (Figure 47), while only minimum ulnar deviation increased significantly for both wrists.

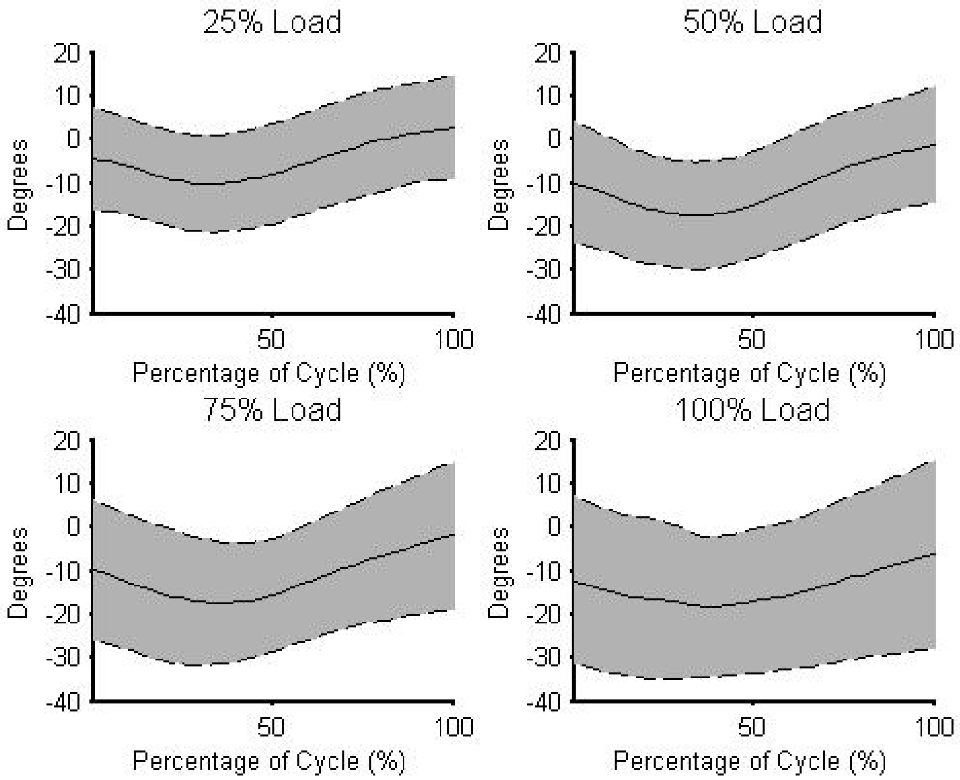


Figure 47: Mean wrist flexion/extension angle of the right arm with +/- one standard deviation during all sets of the waist to overhead lift. Wrist extension increased with load.

4.4.5 Overhead Work

As time increased in the overhead work task, all measured joints saw kinematic changes in order to continue performing the task. With respect to the torso, only flexion/extension angle changed with intensity. Mean extension angle increased from 6.4° in the first 30 seconds to 13.3° in the last 30 seconds (Figure 48).

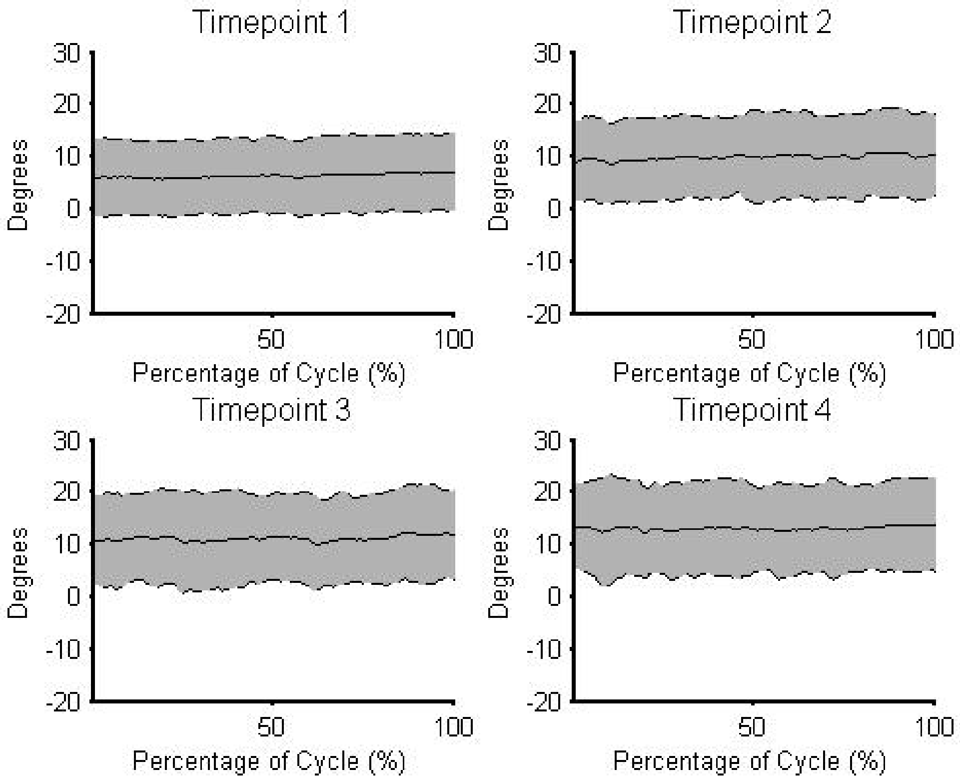


Figure 48: Mean torso flexion/extension angle with +/- one standard deviation for each time point of the overhead work task. Extension increased with time.

All three degrees of humerothoracic angles were affected as the overhead work task was performed to maximum capacity. Abduction angle decreased significantly in only the left arm, but flexion/extension and axial rotation differences reached significance for both sides. Mean humeral flexion gradually decreased from a mean 62° for both arms in the first time point to 57° for the right arm and 52° for the left arm in the final time point. The most substantial change was the decrease in external rotation of the humeri (Figure 49). In the first 30 seconds, the right and left arms were held in an external rotation posture of approximately 36.41° and 32.58°, respectively. As the participants reached their maximum capacity, the amount of external rotation decreased to 22.83° and 18.32°.

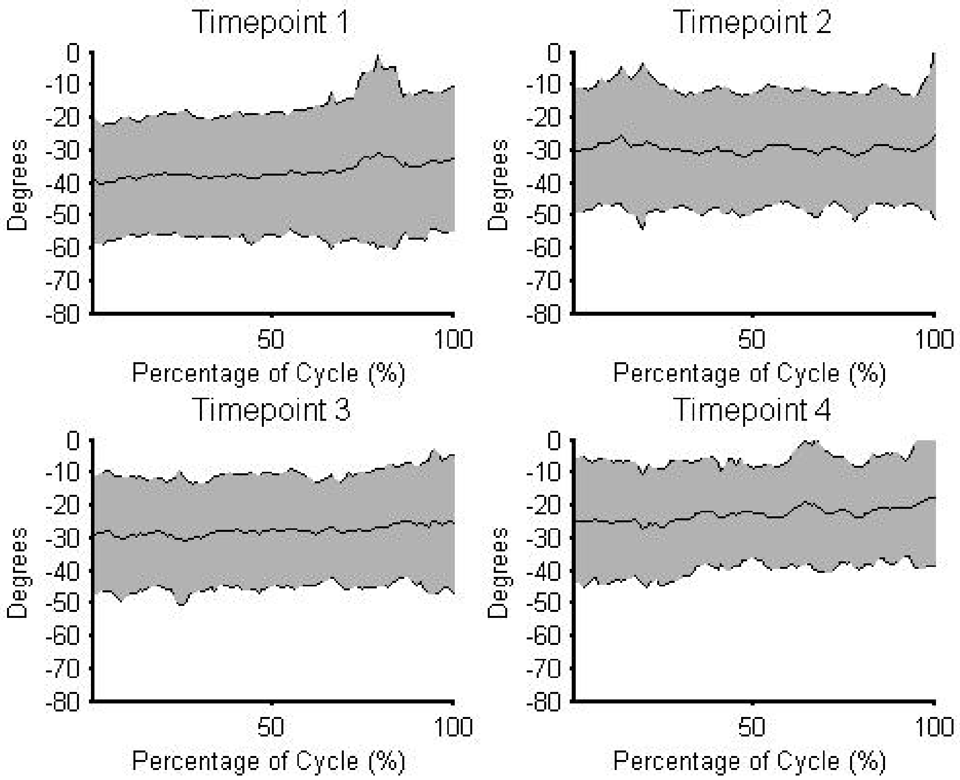


Figure 49: Mean humeral axial rotation angle of the right arm with +/- one standard deviation for all time points of the overhead work task. External rotation decreased from the first 30 seconds to the last 30 seconds.

Elbow flexion/extension also changed significantly from the first 30 seconds to the last 30 seconds. In the first time point the right and left elbow were held at an average of 67.65° and 81.45° and gradually increased to 76.73° and 91.82°, respectively (Figure 50). Pronation remained around 90° and 100° for the right and left side, respectively, for the whole task.

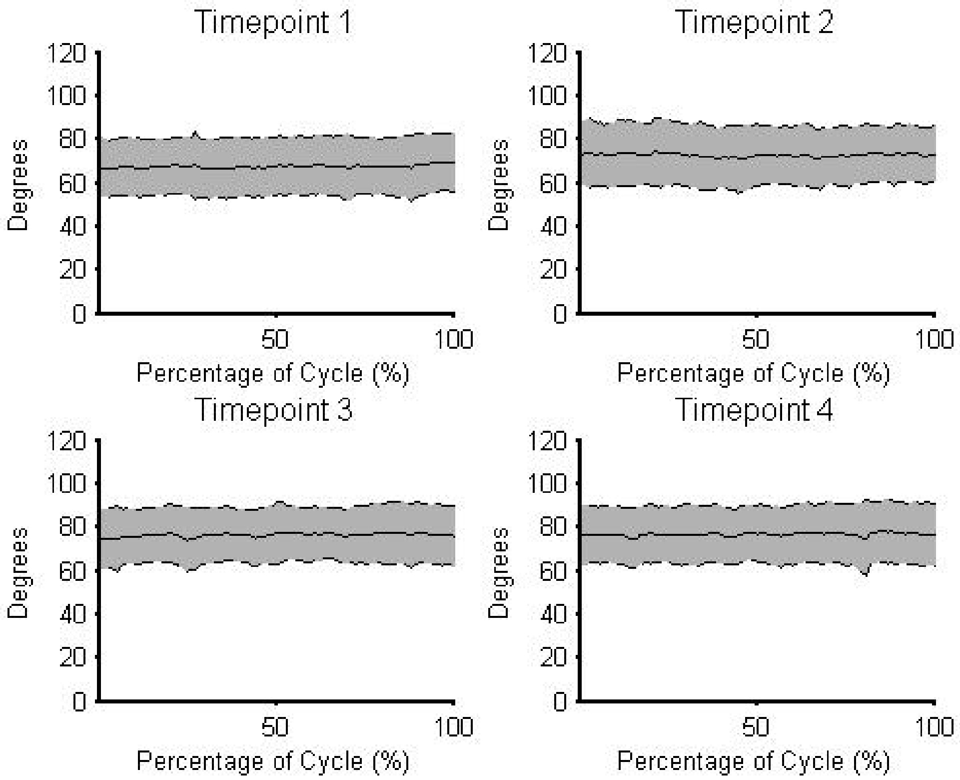


Figure 50: Mean elbow flexion/extension angle of the right arm with +/- one standard deviation during the overhead work task. Flexion angle gradually increased with time.

Finally, wrist flexion/extension also changed with time. Mean right and left wrist extension increased from a neutral wrist posture to 9.13° and 18.39° of extension (Figure 51). Ulnar deviation remained at an average of 9.53° and 22.35° for the right and left wrist, respectively, for the entire task.

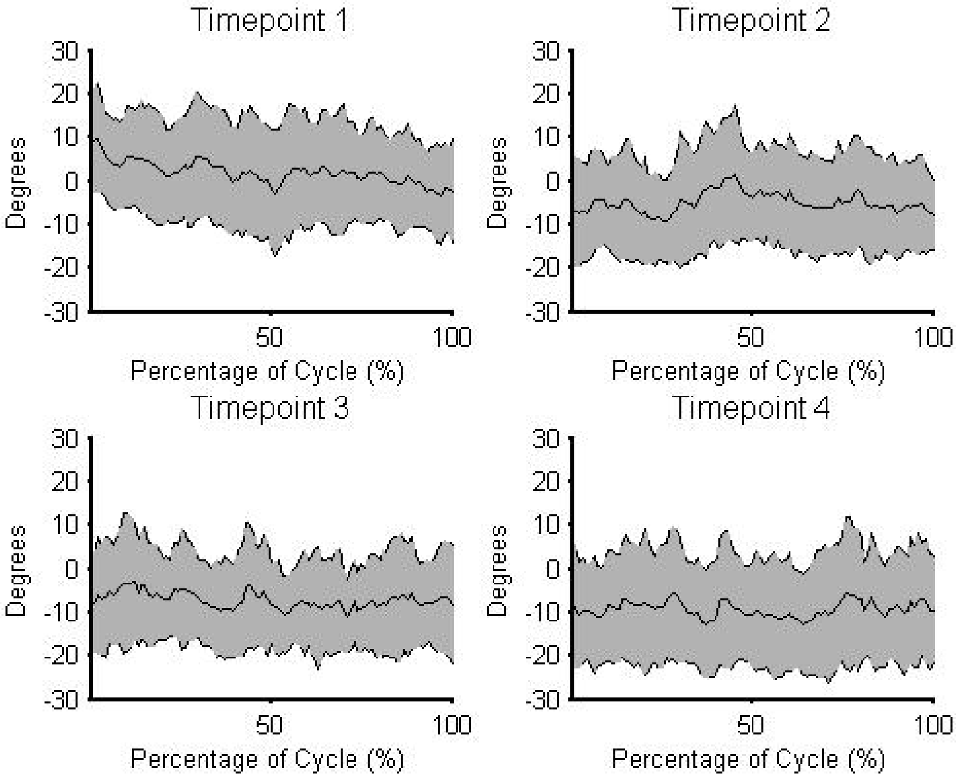


Figure 51: Mean wrist flexion/extension angle of the right arm with +/- one standard deviation during the overhead work task. Extension increased with time.

Chapter 5: Discussion

The aim of this investigation was to produce a comprehensive description of upper extremity and torso kinematics during select Functional Capacity Evaluation (FCE) tasks. The establishment of normative kinematic data for upper limb focused FCE tasks may improve evaluator's return to work decision making. The ability to compare a patient's movement strategies to a normative dataset enables evaluators to better screen and identify potential movement compensations or aberrations that could increase injury risk if the patient returns to work in that state. Used in conjunction with normative capacity data, this normative kinematic data will allow evaluators to gain a better understanding of a patient's ability to return to work and any limitations they may have.

The results indicate that these tasks are useful for evaluating upper limb injuries, especially shoulder related injuries due to the large range of motion required and high demand postures used by healthy participants to complete these tasks. The results also support the use of the kinesiophysical approach to FCE assessment; that is, the assessment strategy that relies on evaluator observation of mechanics to determine maximum capacity and to distinguish between safe or unsafe kinematics.

The discussion organized into three sections. First, the capacity results are addressed and compared to current data. Next, the hypotheses are reviewed in the context of the results of the current study, and finally the normative data is compared to current literature and evaluated using commonly used observation analysis tools.

5.1 Capacity Data

Capacity data is the standard outcome of an FCE and previous work has created a normative capacity dataset (Soer, et al., 2009). While the normative capacity dataset used similar tasks as the current investigation, not all subtasks are directly comparable. It is not clearly stated if the repetitive reaching task is performed in both directions or which of the Minnesota Manual Dexterity Test tasks were performed in the protocol of Soer et al. (2009). Additionally, only the right and left hand tasks of the fingertip dexterity tasks were performed in the Soer protocol. Nonetheless, the capacity scores from the current study met or exceeded the average normative values for corresponding tasks from a larger normative dataset collected from working, healthy subjects (Soer, et al., 2009). Minor capacity discrepancies between the two studies likely emerges from population differences; in Soer et al. (2009) the age range of healthy participants was 20 – 60, while in the current study it was 20 – 27 years of age.

5.2 Hypotheses

5.2.1 Hypothesis One

Contrary to hypothesis one, sex did not influence kinematics or velocity for any task. This is the first investigation to measure these specific tasks, but sex differences have been reported for other movements and joints. For instance, differences between males and females were found for peak torque, peak joint displacement and time to peak angles for the knee joint during landing and cutting tasks (Jacobs, Uhi, Mattacola, Shapiro, & Rayens, 2007; Schmitz, Kulas, Perrin, Riemann, & Shultz, 2007). Additionally, evidence suggests that variables such as velocity, acceleration, force, and power are also influenced by gender in some lifting tasks (Stevenson, Greenhorn, Bryant, Deakin, & Smith, 1996). However, the sex differences found could be partially due to the fixed height of the lift in Stevenson et al. (1996); as female stature is generally smaller, a different strategy than males could be required to lift the box to the same height.

Indeed, stature differences may explain many of the kinematic differences between sexes recorded in the literature. In standardized computer tasks, shoulder external rotation and range of motion of the shoulder and wrist were higher for women (Won, Johnson, Punnett, & Dennerlein, 2009). However, when participants were grouped by anthropometry instead of sex the differences between groups of different stature were even more pronounced than the differences between sexes. Additionally, when stature is accounted for in a reaching tasks in a simulated driving scene, differences between males and females were reduced to only 3° (Chaffin, Faraway, Zhang, & Woolley, 2000). Therefore, because the FCE tasks in the current study were scaled proportionately to each participant's anthropometry, sex differences may be irrelevant.

It was hypothesized that observed sex differences could be partially due the known larger range of motion of females for many joints, indicating there is a potential for different movement strategies attributable to the differences in available range of motion (Barnes, Van Steyn, & Fischer, 2001). It is possible that sex differences were absent from the current study because movements required for all tasks were within a range of motion available to both males and females.

5.2.2 Hypothesis Two

Hypothesis two stated that load magnitude and task duration, also referred to as intensity level, would influence kinematics in the waist to overhead lift and overhead work task. Kinematics of all 7 joints were altered as intensity of the tasks increased.

5.2.2.1 Waist to Overhead Lift

In the overhead lifting task, torso flexion/extension, minimum humeral flexion, wrist extension and minimum wrist ulnar deviation increased with load. Both the increase in torso flexion and increase in humeral flexion occurred at the start of each lift cycle, indicating that participants addressed the crate differently at heavier loads. This suggests that for heavier lifts, healthy young adults decrease the contribution of their arms to the lift and shift the load to the back muscles, as demonstrated by the increased range of motion of the trunk. These results are consistent with those of Chen (2000) who noted that after fatigue in both floor to knuckle and floor to shoulder lifts, participants used a more stooped posture while stiffening their arms in order to transfer work to the back and hips. However, this strategy is contraindicated for several reasons. Resistance to shear force decreases in a flexion posture (Howarth & Callaghan, 2012) and injury to the spine is influenced strongly by the degree of torso flexion (Potvin, McGill, & Norman, 1991). Further, the increased torso flexion combined with the increased shoulder flexion moves the load farther from the body, increasing the load on both the shoulder and the low back (Waters, Putz-Anderson, Garg, & Fine, 1993). In addition, the rise in torso extension is undesirable because movement of the spine away from neutral increases trunk extensor activity, spine compression and shear force on the spine (Arjmand & Shirazi-Adl, 2005; Callaghan, Gunning, & McGill, 1998). Finally, all measures of wrist extension increased with load, as did minimum ulnar deviation values indicating that participants maintain a more ulnar deviated wrist posture for the entire lift at the heavier loads. The changes in extension and ulnar deviation increase stresses on the carpals and tissues crossing the wrist, which can increase injury risk (Oatis, 2004).

Although these changes are normal adaptations to increasing demand, the implications of the changes are still important for evaluators to understand. When these changes become evident, this level of demand should be noted as maximum capacity and return to work recommendations can be made (Isernhagen, 1992).

The results of the current study are consistent with changes seen at maximum load during another FCE protocol's overhead lift task. Allan, James, & Snodgrass (2012) evaluated the effect of load on the overhead lift in another FCE system, the WorkHab FCE. Similar to the current study, spine extension increased, shoulder extension decreased at the beginning of the lift, and ulnar deviation increased across the entire lift. Some discrepancies between Allan et al. (2012) and the current study include a decrease in elbow flexion and an increase in shoulder flexion throughout most of the lift during the WorkHab protocol. It is suggested by Allan et al. (2012) that these changes occur to compensate for the increase in spine extension in order to continue to place the box at the required height. In the current study, the same increase in torso extension occurred, but no significant changes occur in elbow extension or humeral flexion past the beginning of the lift. Other compensations could have occurred in the current study to ensure the box was placed at the required height such as raising up onto the toes to raise the whole-body centre of mass.

Mean and peak velocity were also influenced by load in the waist to overhead lift task. Torso velocity increased with load, while velocity of all 6 arm segments had an inverse relationship with load. The velocity trade-off between the torso and arms indicates that as participants lift heavier loads, they rely more on torso motion than arm motion to lift the box. These results are consistent with previous literature; Marras et al. (1993) identified increased trunk sagittal velocity to be one of the top variables that distinguished high risk groups from low risk groups during a floor to waist lift.

5.2.2.2 Overhead Work

The current work is one of a few investigations that has evaluated kinematics and kinematic changes during a prolonged overhead work task. As participants reached maximum capacity in this task, several kinematic changes occurred: increased torso extension, decreased humeral flexion, decreased humeral external rotation, increased elbow flexion, and increased wrist extension. Shoulder moment decreases when working closer to the midline of the body (Anton, et al., 2001), so it is possible that decreasing humeral flexion and increasing elbow flexion could be an effort to bring the hands closer to the midline of the body and decrease the shoulder moment. Further, because the hands were in a somewhat fixed position in front the body, the decrease in external rotation manifests as raising the elbows outward. This compensation could be an effort to shift physical demands to larger muscles like the middle deltoid and trapezius (Kronberg, Nemeth, & Brostrom, 1990).

Mean velocity increased for all segments as maximum capacity was reached during the overhead work. An increase in velocity in a prolonged posture task likely indicates more movement at each joint to maintain task performance. Increasing movement reflects an ability to utilize the redundancy of the body by shifting demands to different muscles to prolong the ability to perform the task (Mathiassen, Moller, & Forsman, 2003). This strategy has been documented in healthy control subjects performing repetitive tasks (Coté, Raymond, Mathieu, Feldman, & Levin, 2005; Lomond & Cote, 2011a).

Many of the above mentioned kinematic changes may be protective. The decrease in humeral flexion coupled with the increase in elbow flexion indicates a potential attempt to decrease shoulder moment (Anton, et al., 2001). Additionally, the higher in mean velocity of all segments during the later time points reflects an attempt to lessen exposure to any one joint or muscle; an injured patient may not be able to benefit from the redundancy and would present a more fixed position strategy, causing an increased load on the structures used to maintain the posture (Coté, Raymond, Mathieu, Feldman, & Levin, 2005; Lomond & Cote, 2011).

Conversely, the changes in torso extension and external rotation of the humeri are potentially negative compensations. Torso extension the increases demand on the back extensors and forces at the spine (Arjmand & Shirazi-Adl, 2005), while the decrease in external rotation of the humeri places the arms in postures commonly associated with shoulder impingement

(Graichen, et al., 1999). This alteration also required participants to increase wrist extension to keep the hands in the same position, causing a change from neutral to more deviated posture.

5.2.2.3 Differences between Intensity Levels

Hypothesis two anticipated that the largest differences would exist between the baseline and maximum capacity and this was overwhelmingly the case for the kinematics for all joints and velocities for all segments. Therefore, even if changes in body kinematics are assigned the same category or score, evaluators could still be able to observe the changes from the initial movements or postures (Corlett, Madeley, & Manenica, 1979). However, the amount of change from the first set or time point to the last set or time point was inconsistent across joints and variables, so gradual changes may be difficult to interpret because there it is not clear what amount of change is relevant, making it difficult to identifying an absolute angle or absolute amount of change that would represent maximum capacity. However, these normative profiles and kinematic data identify trends of kinematic changes, that when used with other observable aspects of performance such as sweating, facial expressions, or muscle tremor (Chappell, Henry, McLean, Richardson, & Shivji, 2006) can provide improved guidance for identifying maximum capacity or “unsafe” movement.

The importance of identifying these changes is twofold: 1) when evaluators observe these compensations it is an indication that maximum capacity is reached and the test should be terminated, or 2) if they observe different compensations from patients with injuries, this indicates that the injury could be forcing them to alter their kinematics to a postures or movements with higher injury risk to the uninjured joints or structures. Most importantly, if patient’s exhibit these movement compensations at a capacity level that is below the load that is required for their job, this is a strong indication that patients are not ready to return to work.

5.2.3 Comparison to Current Guidelines

A large portion of patient evaluation in the FCE is the ability to distinguish between effort levels and safe or unsafe kinematics. When using the kinesiophysical approach, understanding movement and kinematic changes is of utmost importance, but currently the information and guidelines for observation and evaluation are vague. However, though vague, the current guidelines seem to coincide with the results of the current study. For instance, the guidelines for a floor to waist lift state that for a maximal lift an evaluator would see marked counter balance and use of controlled momentum (Reneman, Fokkens, Dijkstra, Geertsen, & Groothoff, 2005). These phenomena could be represented in the waist to overhead lift by increased torso flexion at the beginning of a lift and subsequent increased maximal extension at the height of the lift. These increased peaks and increased range of motion, in conjunction with the increased torso mean and maximum velocity, could be described as the use of momentum and counter balance.

For the overhead work task, the guidelines are less specific, which is common for the observation criteria for any non-manual materials handling task. Even so, the criteria directs evaluators to watch for “substantial deviations from normal posture and substantial unrest” (Trippolini, et al., 2014a, p. 368). The current study noted several changes in posture, such as increased back extension and humeral rotation, which would represent the substantial deviations from normal posture. In addition, the increase in mean velocity of all segments during the work task indicated more movement in all segments while maintaining hand location, potentially reflecting substantial unrest and frequent changes in posture.

5.3 Normative Profile Evaluation

The tasks in this study were specifically chosen to simulate work tasks and to test motion relevant to upper limb function. However, the kinematic requirements of these tasks have yet to be evaluated from an ergonomics perspective and doing so would provide unique insight into these common FCE tasks and their approximate demand levels. This section evaluates the kinematic profiles, including scoring all motion and postures using commonly available observation tools such as the NIOSH Observation-Based Posture Assessment (NIOSH, 2014), the Rapid Upper Limb Assessment (RULA) (McAtamney & Corlett, 1993) and stressfulness ratings by Genaidy, Barkaw, & Christensen (1995). This strategy for evaluation serves two purposes; the first is to provide context to the movements and postures of the selected tasks and the second is to provide commentary on these observation tools.

Each of the above mentioned tools have different classification and scoring schemes to evaluate postures. The NIOSH document includes a review of observation based assessment that identifies posture categories of 30° to be the optimal bin size because magnitude of errors and number of errors converge at the combined lowest values when observation bins of this size are used (NIOSH, 2014). This strategy of classifying movements into 30° bins can be applied for directions of movement and angles that are not included in the document, and is a particularly useful strategy for kinematic assessment during an FCE as classifying postures into categories would likely improve consistency of evaluations and allow for easier interpretation. Both RULA and the Genaidy et al. (1995) can provide guidance for the understanding of high risk postures. RULA requires classifying the most stressful posture used into categories with various scores; the more stressful the posture, the higher the score. RULA categories often span from one to four, with potential for added points for motion not in the sagittal plane. A score of one means this is a posture with the least musculoskeletal demand (McAtamney & Corlett, 1993). The posture categories for RULA are not consistent in size within or across joints, but it is a tool often used in ergonomics assessment. Genaidy et al. (1995) rates postures based on the discomfort and stressfulness compared to neutral, with scores ranging from one to seven. The

Genaidy et al. (1995) ratings are coarse but provide insight into the stressfulness of the motions and postures.

5.2.1 Torso Angles

In all reaching and dexterity tasks, torso flexion angle was similar and remained consistent throughout each trial. For the repetitive reaching task, fingertip dexterity, and hand and forearm dexterity tasks, torso flexion would fall in the NIOSH first category (0°-30°) and would be scored up to a three using RULA. Based on Genaidy et al. (1995) this posture would be rated up to a three for stressfulness. These scores are relatively low, indicating torso flexion required in these tasks is minimal.

Evaluation of torso flexion/extension for the waist to overhead lift and overhead work was not straightforward. During the lift, the participants began each cycle in the first NIOSH category (0°-30°) of trunk flexion and would score a two from RULA. However, trunk angle quickly transitioned to an extension angle of up to approximately 25° for some participants. In addition, postures up to 20° of extension were used in the overhead work task. Increasing extension from neutral would likely have a similar increasing risk as increasing flexion (Punnett, Fine, Keyserling, Herrin, & Chaffin, 1991), but extension is not highlighted in popular tools used for posture analysis. Torso extension is a posture that would increase injury risk and consequently is important to monitor during the overhead work tasks. Using the NIOSH document observation bin sizes, the healthy participants in this study always exhibited extension in first category (0°-30°), although significant changes could be observed within the category as load increased. RULA only suggests a score of one when the hip-trunk angle is greater than 90° and is well supported. Finally, Genaidy et al. (1995) indicates that the stressfulness of any amount of lower back extension is a three out of seven. According to these evaluation tools the level of torso flexion/extension is low in these tasks, but the changes observed in these tasks indicate that this angle is important for identifying effort levels. Also, due to the injury risk that comes with increasing flexion and extension, these angles should closely monitored for deviations.

Lateral flexion was not markedly different from neutral for any tasks. Lateral flexion of the torso results in awkward postures that increase muscle co contraction, spine compression, and intradiscal pressure (Pope, Goh, & Magnusson, 2002) but likely not at the level required in these tasks. Lateral flexion during all tasks was always in the first NIOSH category (0°-15°) with only the direction of movement changing with task. RULA suggests adding one point to the flexion score for trunk lateral flexion, while Genaidy et al. (1995) notes that lateral bending results in a stressfulness ranking of five out of seven, however it is not indicated how much lateral flexion is need to reach this stressfulness level. Overall, the level of lateral bending in these tasks is negligible.

Axial rotation was different from neutral for many tasks in this investigation but would still be classified in the smallest NIOSH category (0°– 30°) for most tasks. In contrast, the axial rotation observed in the repetitive reaching task would be classified into the second NIOSH category (30°– 60°). Torso axial rotation motion has been identified as a factor that would affect injury risk (Marras, et al., 1993) and when combined with torso flexion, which is the case in most tasks, axial rotation can increase strain on the spine (Shirazi-Adl, Ahmed, & Shrivastava, 1986). However, RULA only suggests adding one point to the flexion score for any degree of rotation and Genaidy et al. (1995) only rates trunk rotation a stressfulness score of two out of seven. According to these results, the current level of axial rotation in most tasks is low but this angle should be closely monitored for changes that would indicate potential negative compensations. Also, axial rotation in the repetitive reaching task is higher than other tasks, indicating that is task would be useful in evaluating that motion.

All torso postures, with the exception of torso axial rotation in the repetitive reaching task, would be classified in the closest posture category to neutral of the NIOSH document. These tasks are relatively low risk for the torso, as expected, because these tasks were chosen to evaluate the upper limb. This also means that patients with upper limb or shoulder injuries could increase torso motion to compensate for injuries. Compensations in torso motion were already apparent with intensity changes in the healthy participants tested, indicating similar phenomena are also likely with injured patients in other tasks. Lomond & Cote (2011b) noted analogous changes in shoulder-injured individuals compared to healthy participants; in a repetitive reaching task, shoulder injured individuals decreased shoulder and elbow ROM, likely in a pain minimizing strategy, but compensated by increasing centre of mass ROM. Unfortunately, classifying all torso flexion/extension motion in the first category results in some complications; the significant changes in both torso flexion and torso extension are masked with this classification system. However, because all changes were gradual increases, it is possible that they could still be observed by evaluators even if they are within the same category. As the lightest intensity is always the first set or beginning of the task, this could act a reference angle for the evaluators.

5.3.2 Thoracohumeral Angles

Humeral motion during the tasks of this investigation spanned a much larger range of motion than the torso.

High levels of arm elevation were required in all of the current FCE tasks. According to the NIOSH category, the maximum humeral abduction posture during all the reaching and dexterity tasks would belong in the second category (30°-60°). Humeral flexion would also be placed in the second category (30°-60°) for the fingertip dexterity and hand and forearm dexterity tasks, while the repetitive reaching task maximum shoulder flexion posture would reach the third category (60°-90°). RULA scores are high for these tasks as well. Using the RULA system, arm angle is rated based on the sagittal angle and one point can be added for arm abduction, regardless of the level of abduction. Therefore, all of reaching and dexterity tasks would receive up to a four for being greater than 45° of elevation and being abducted. During the waist to overhead lift, abduction angle reaches up to the 150° while the final flexion angle belongs in the second NIOSH category (30°-60°). The overhead work task also required a high level of abduction, however the range of standard deviation from the mean was quite large; healthy participants used anywhere from 60°-120°, or the third and fourth NIOSH categories. Participants had a flexion angle that belongs in the third (60°-90°) NIOSH category during the first time point of the overhead work task, but as time went on, flexion angle dropped to the second category (30°-60°). Using RULA, both of these overhead tasks would score up to a five. When considering the more basic scale of stressfulness form Genaidy et al. (1995) these actions would score up to seven out of seven.

According to these evaluation tools, the arm elevation required to complete all selected tasks of this investigation is high. Arm elevation is a high risk motion and increasing elevation angle is correlated with increased incidence of shoulders injuries (Silverstein, et al., 2008; Svendsen, Bonde, Mathiassen, Stengaard-Pederson, & Frich, 2004). Nevertheless, many different occupations require a high level of arm elevation (Frings-Dresen & Sluiter, 2003; Punnett, Fine, Keyserling, Herrin, & Chaffin, 2000; Svendsen, Mathiassen, & Bonde, 2005). Therefore, shoulder abduction and flexion are important motions and postures to assess and these tasks allow evaluators to test a patient's abilities and movement strategies in these planes. In addition, these angles exhibit changes due to intensity level that can be used to determine effort level and maximum capacity during the overhead tasks.

Humeral axial rotation is also a significant angle to analyze when assessing shoulder motion. For instance, axial rotation changes significantly with time during the overhead work task and therefore should be monitored to classify effort and capacity level. Because the hands are at a fixed position the increasing internal rotation of the humerus manifests as raising the elbows up and out (Figure 52). This position could shift the burden from the anterior deltoid to the middle deltoid and supraspinatus (Kronberg, Nemeth, & Brostrom, 1990). In addition, the abducted and internally rotated posture of this task is one that increases tissue contact with the acromion, a condition that causes shoulder impingement (Brossmann, et al., 1996), indicating this a posture that would likely be avoided by shoulder injured patients, meaning they would likely use different movement compensations to continue performing the overhead task as they fatigue.

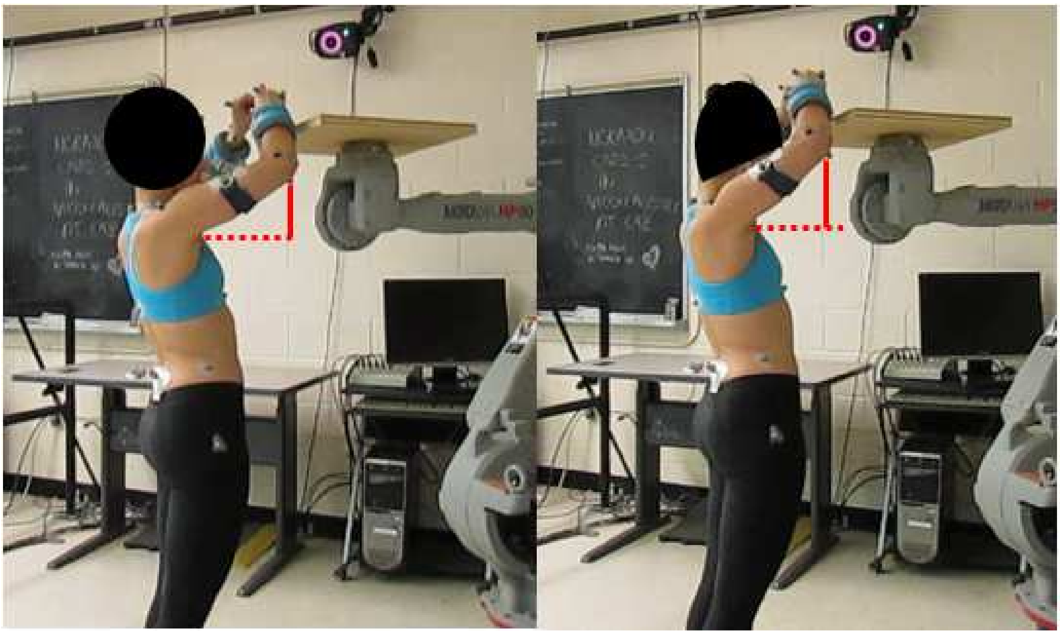


Figure 52: Arm posture during the first 30 seconds (left) and the last 30 seconds (right) of the overhead work task. The elbows move up and outwards as the humeral internal rotation increases, as illustrated by the longer solid line and increased arm angle relative to the dotted line in the second picture.

Another example of observable axial rotation changes are during the fingertip dexterity and hand and forearm dexterity tasks. During pin and block placement internal rotation increases and the increase can be observed as a lift of the elbow (Figure 53). Patients with any sort of disorder in the subacromial region would likely avoid this position because the increasing internal rotation in conjunction with an abducted arm, places the arm within the range of the painful arc. The painful arc occurs between 60° and 120° of arm abduction. Pain that exacerbated when the arm is in this range of abduction is an indication of a disorder in the subacromial region (Kessel & Watson, 1977). Thus, this is an aspect of upper limb kinematics that could be used to distinguish between normal or abnormal kinematics; for instance, patients with subacromial disorders performing this FCE protocol could use a more externally rotated humerus or increase motion at joints other than the shoulder to avoid the painful arc, subsequently increasing load on those structures (Kessel & Watson, 1977; Lomond & Cote, 2011b).

Figure 53: Arm position as the arm moves to the correct hole in the pegboard (left) and during pin placement (right) in the FD task. The arm moves up and out, as seen by the distance between the red line and the elbow, during pin placement and internal rotation increases.

Even though humeral axial rotation is an important motion for distinguishing between effort levels and a potential area for identifying deviations from normal, this angle is not included in either RULA or the stressfulness ratings (Genaidy, Barkaw, & Christensen, 1995). Using the 30° posture categories, both the repetitive reaching task and waist to overhead lift task would span several categories, as axial rotation spanned from approximately 50° of external rotation to 100° of internal rotation and 100° of external rotation to 50° of internal rotation, respectively, although this change in angle is difficult to observe (Figure 54). In fingertip dexterity and hand and forearm dexterity tasks, axial rotation would be classified into the second internal rotation category (30°-60°). Finally, during the overhead work task, external rotation would be categorized into the second NIOSH category (30°-60°), although decreases in external rotation occur within the same classification.

Figure 54: Arm position during marble pick up (top) and marble drop off (bottom) during the RRT task. Axial rotation spans from approximately 50° of external rotation to 100° of internal rotation but these changes are difficult to observe in this task.

The motion and postures used by a healthy population in these FCE tasks supports use of these tasks in evaluating abilities of the upper limb. The changes in all three thoracohumeral angles during the overhead tasks emphasizes the importance of monitoring the upper arm to identify maximum capacity and the large ranges of motion and higher risk postures used in all tasks indicates these are important angles to examine during evaluations. It is likely that shoulder injured individuals would exhibit compensations because of the high demands on the shoulder in these tasks. Some of these, such as avoiding placing the arm in the painful arc (Kessel & Watson, 1977; Brossmann, et al., 1996), are discussed above but other possibilities for injured individuals to deviate from normal exist. For instance, in the repetitive reaching, a large range of both humeral abduction and flexion are used and in a short period of time; an average of 60 reaches in a minute. This range of motion may not be available to shoulder injured individuals, especially when combined with fast movement, and thus, they could compensate for this lack of range of motion by increasing torso axial rotation in order to still reach to the same relative position (Figure 55). During the overhead tasks, injured patients may not be able to elevate the upper arm to the required height due to injury or pain (McClure, Michener, & Karduna, 2006), prompting compensations at the adjacent joints or potentially an inability to perform the task at all. Specifically, injured or previously injured patients performing the overhead lift could exhibit greater torso extension and increased elbow extension to compensate for the lack of ability to elevate the arms to the required height (Allen, James, & Snodgrass, 2012). Compensations such as these may decrease the demand on the shoulder but could escalate the low back moment by increasing the horizontal distance of the load from the body (Waters, Putz-Anderson, Garg, & Fine, 1993). The same compensation could be seen in the overhead work task, leading to the same issues. Finally, injured patients will likely perform the reaching and dexterity tasks slower, resulting in decreased capacity scores and decreased segment velocities.

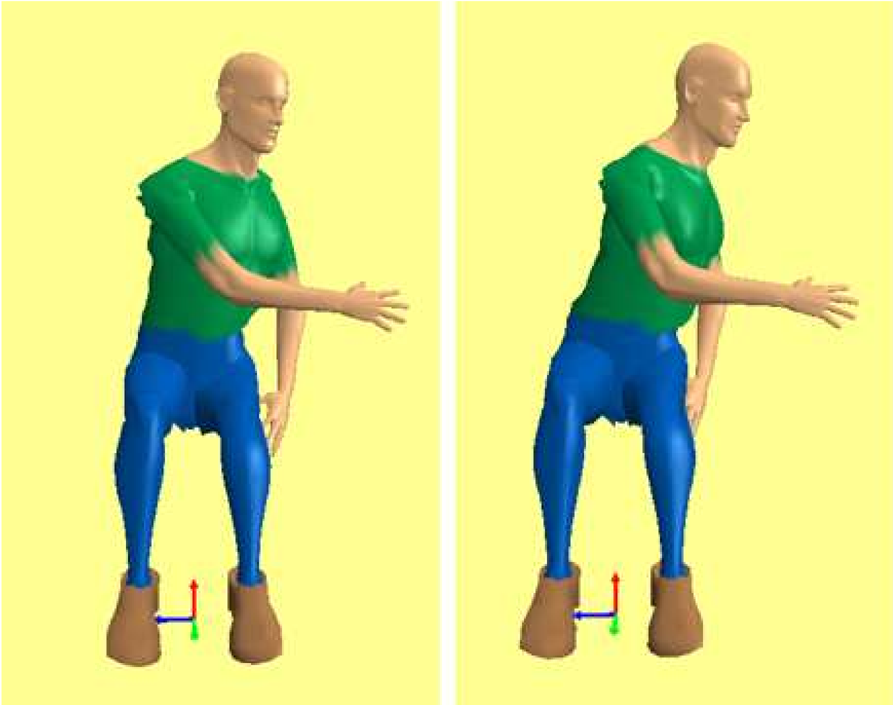


Figure 55: An illustration of the strategy used by healthy participants (left) and potential compensations available to shoulder injured individuals (right) in the repetitive reaching task. A decreased range of motion at the shoulder in combination with shoulder pain may cause participants to rely on torso motion, specifically increased axial rotation, to place the hand at the required position in this task.

5.3.3 Elbow Motion

According to RULA scoring, most of the elbow motion during the reaching and dexterity tasks is relatively low risk. Elbow flexion would be scored only a one during the fingertip dexterity task, while the repetitive reaching and hand and forearm dexterity tasks would receive a two. Using the NIOSH categories, all reaching and dexterity tasks would be within the third and fourth posture categories (60° – 90°/90° – 120°), except of the placing task that would span the second, third and fourth categories during one cycle (30° – 60°/60° – 90°/90° – 120°) The setup of the NIOSH categories would suggest that as the elbow moves from neutral, the posture becomes higher risk, but this seems to be in conflict with the RULA guidelines. Kroemer & Grandjean (1997) noted that it is best practice for both strength and skill for the elbow to be bent at right angles, so a bent elbow posture is considered the preferred posture for the elbow in this investigation. The waist to overhead lift required elbow flexion that spanned all four NIOSH categories, although this motion would only receive a score of two on a RULA scale. During the overhead work task, elbow flexion would also receive a score of one based on the RULA guidelines, although flexion does increase with time within that range, and would be classified in the third NIOSH category for most participants. Finally, Genaidy et al. (1995) only suggests a score of three out of seven for elbow flexion at any level. Overall, elbow motion seems to be of lower importance based on the scoring from the observation tools and most motion during these tasks is within the preferred range.

Pronation angle is similar for all tasks except for the overhead lift. Using Euler angles, full supination, or anatomical position, of the forearm is 0° and increasing angle represents pronation. Most tasks are performed with approximately 130° of pronation, while the waist to overhead lift begins with about 90° of pronation as the participants grab the box handles and ends with almost full supination. Pronation angle is not included in RULA or NIOSH documents, but Genaidy et al. (1995) found pronation to be considerably less stressful than supination (a score of 3 compared to 6) and Kroemer & Grandjean (1997) noted that the hand is more powerful in pronation that supination.

Elbow angles throughout most tasks of the current study was within the strongest, most comfortable region. This suggests these tasks are ergonomically sound when considering the elbow. With the exception of both overhead tasks and the hand and forearm dexterity placing task, elbow flexion/extension range of motion was relatively low and within the lowest risk category of RULA. Since these tasks are not elbow demanding, they would not be as effective for screening elbow injuries. Instead, this joint could be one that could compensate for lack of motion due to injury or pain.

5.3.4 *Wrist Angles*

Wrist motion was different from neutral for many of the FCE tasks in this investigation. Although the motion at the wrist was not as high as the rest of the upper limb, the available range of motion at the wrist is smaller than the available range for the elbow, shoulder, and torso. Flexion/extension range of motion of the wrist is from approximately 80° flexion to 60° extension, while wrist deviation ranges from approximately 20° of radial deviation to 40° ulnar deviation (Ryu, Cooney, Askew, An, & Chao, 1991). The NIOSH document does not have wrist postures classified into categories but the standard 30° category size may not be relevant due to the smaller range of motion of the wrist. RULA has limited scoring for the wrist, while the strain index, a commonly used tool to evaluate the lower arm, includes scoring guidelines for wrist postures with categories such as “neutral” and “near neutral”, “non neutral”, “marked deviation” and “near extreme”.

Wrist flexion/extension angle varied with task. Healthy participants used mostly neutral or near neutral flexion/extension wrist postures during the dexterity tasks, resulting in a score of one from the strain index and up to two from RULA. The repetitive reaching task was an exception and required more wrist motion than the dexterity tasks, receiving a score of three from RULA, non-neutral classification from strain index and up to a three on the stressfulness ratings (Genaidy, Barkaw, & Christensen, 1995). The waist to overhead lift would score highest for wrist postures, as up to 40° of wrist extension was used by some healthy participants in the final load, meaning this lift would be classified ‘marked deviation’ from the strain index and three from RULA. Finally, the overhead work also required increasing wrist extension from healthy participants as maximum capacity was reached. The first time point would receive be classified ‘near neutral’ from the strain index and two from the RULA, however in the final time point a ‘non-neutral’ classification and score of three would be appropriate for most participants from the strain index and RULA, respectively.

Almost every task required some level ulnar deviation. The only exceptions were the right wrist during the fingertip dexterity task and the hand and forearm turn task, as the deviation was less than 10° from neutral in these two tasks. Every other task required ulnar deviation from both wrists, so the RULA rating would be the score from flexion/extension plus one point, regardless of the amount of deviation. Similarly, Genaidy et al. (1995) would add two points to the flexion or extension stressfulness rating for ulnar deviation. For all tasks, with the exception of the lifting task, ulnar deviation profiles never reached more than 30°, but considering the maximum range of motion is considered to be 40°, this would indicate ‘non neutral’ or ‘marked deviation’ on the strain index. The waist to overhead lifting task would be classified ‘near extreme’ from the strain index as ulnar deviation was up to approximately 40° for some participants. Ulnar deviation has been implicated in the development of carpal tunnel syndrome and other cumulative trauma disorders of the wrist (Tanaka, et al., 1995; Oatis, 2004), so this level of ulnar deviation in nearly all tasks indicates that this angle should be carefully watched by evaluators for any escalations.

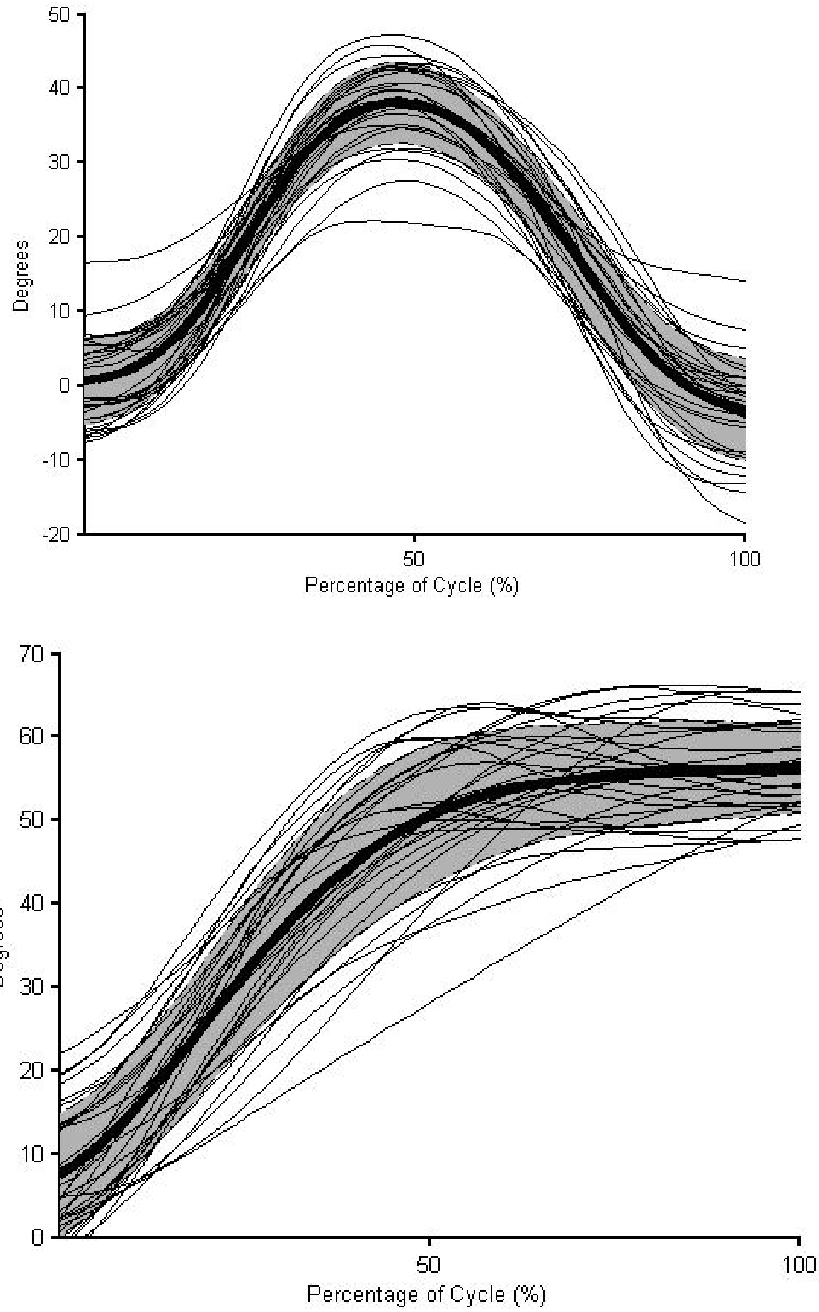
Wrist motion for these tasks is an area of concern, as wrist postures of healthy participants were almost always deviated from neutral. Depending on the patient and the job that they are returning to, the natural inclination to use these postures could lead to injury (De Krom, Kester, Knipschild, & Spaans, 1990). For instance, all participants in the current study used between approximately 10° and 25°of ulnar deviation in the fingertip dexterity task; deviation at that level in an occupation that uses that type of motion repeatedly, such as assembly jobs, could lead to cumulative trauma disorders (Wieslander, Norback, Gothe, & Juhlin, 1989)f. It is unclear how cueing patients to keep a neutral wrist would change kinematics at the rest of the joints but the wrists should be monitored during tasks for even greater deviation.

5.3.5 Evaluation Tool Commentary

Based on the scores from RULA, the stressfulness scale, and the strain index most tasks place the shoulder and wrist in the highest risk postures. However, these tools only provide basic risk scores for the postures, and the validity and utility of some posture analysis methods have been questioned (Bao, Howard, Spielholz, & Silverstein, 2007). The categories and rating scales of these tools are coarse, do not allow for much differentiation between postures and many movement directions are missing or not appropriately represented (McAtamney & Corlett, 1993; Genaidy, Barkaw, & Christensen, 1995; Moore & Garg, 1995). Similarly, the current FCE observation guidelines are coarse and lack specific detail that would allow more consistent differentiation between effort or functional ability categories (Reneman, Fokkens, Dijkstra, Geertsen, & Groothoff, 2005; Trippolini, et al., 2014a). For direction during the observation of FCE tasks, the normative profiles created in this study provide a higher resolution guidelines. For interpretation and real time posture analysis, the recommended 30° posture categories from the NIOSH Observation-Based Posture Assessment would be useful for classifying movement and identifying aberrations from these strategies.

5.4 Application of Normative Profiles

The normative profiles developed in this investigation represent the mean and +/- one standard deviation for a young, healthy population. Thus, approximately 68% of the healthy population would use movement strategies that would fall within the normative profiles, meaning that some healthy individuals could use motion outside the standard deviation bands of the profiles. However, the curves of those individuals that differ from the group profiles would likely have the same trend and shape as the representative profiles (Picco, 2012). To demonstrate this, each participant's raw mean curve is plotted against the mean and standard deviation profile for different joints and tasks (Figure 56). For all examples, the shape of the curves and trend of the movement is consistent for all participants, even if the raw magnitudes are different.



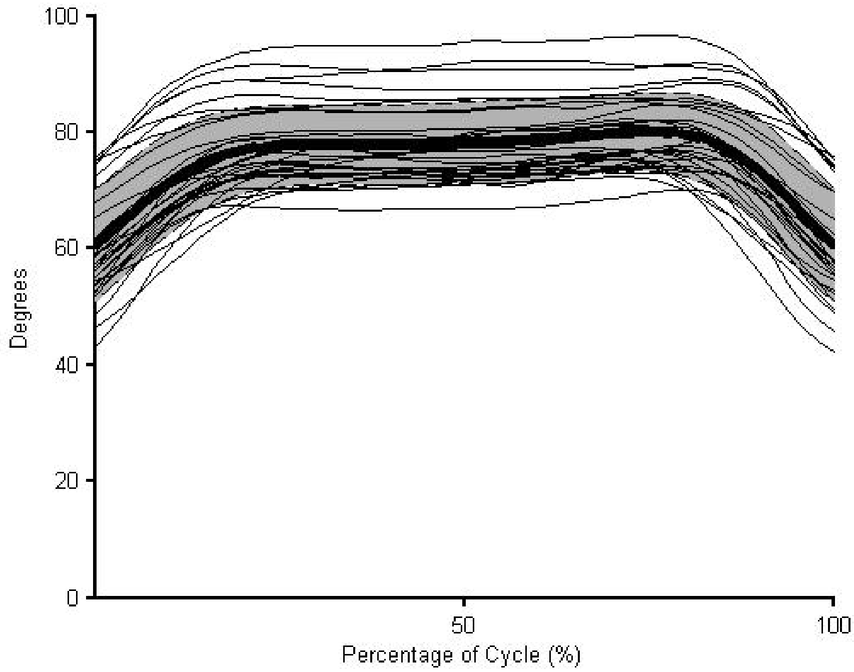


Figure 56: Participants raw mean curves overlaying the normative profiles of torso axial rotation in the repetitive reaching task (top), humeral flexion during the waist to overhead lift (middle) and elbow flexion during the fingertip dexterity (bottom) tasks with the mean of the profiles in bold and +/- one standard deviation shaded in grey.

It is likely injured patients profiles would not match the normative profiles (Winter, et al., 1990). Creating kinematic profiles from known injury populations or different age groups would allow for a more quantitative comparison of the curves to the healthy profiles. For instance, using the example from above, if a patient had a shoulder injury that decreased their available range of motion (McClure, Michener, & Karduna, 2006), it is possible that torso axial rotation would increase during the repetitive reaching task to compensate for the lack of shoulder motion (Lomond & Cote, 2011a). To illustrate this, a hypothetical example of the torso axial rotation of the injured patient is contrasted to the normative profile (Figure 57). Both the magnitude and shape of the curve differ from normal presenting a scenario in which differences could be identified through both statistical measures, such as discrete variable testing or principle component analysis, and evaluator observation.

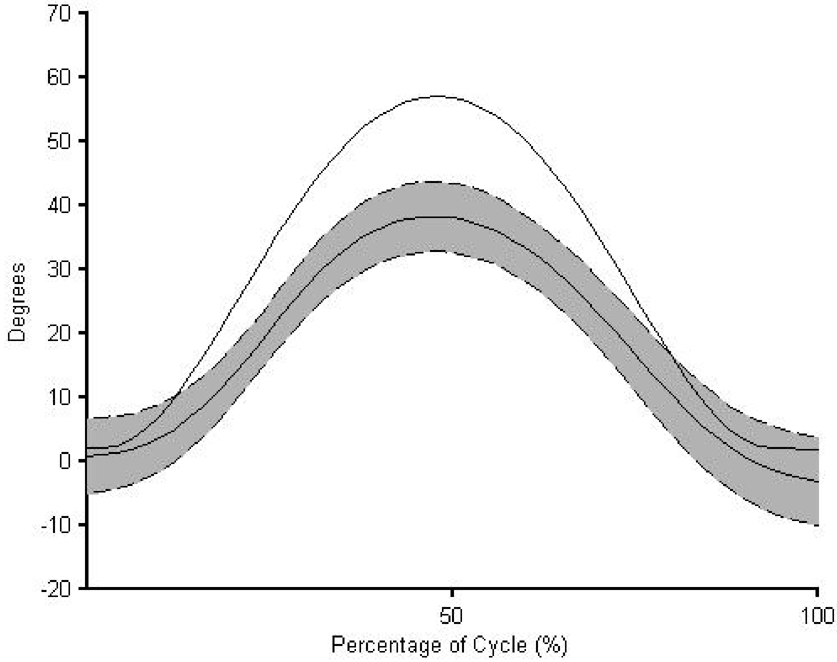


Figure 57: Hypothetical comparison of pathological torso axial rotation to the normative axial rotation profile generated in the current study during the repetitive reaching task.

Individuals could exhibit motion outside of the normative profiles if they are with or without impairment. The implications of the deviations are dependent on the patient and their potential injury, if any. Observation or measurement of deviations from normal would direct evaluators to review the known injury or impairment of the patient being evaluated and to observe motion at other joints in the kinematic chain in order to better understand the implications of deviation. If the trend or shape of motion is consistent with the normative profiles but raw magnitudes differ, it is possible that the patient may be part of the 32% of the healthy population not represented in the normative profiles. On the contrary, if deviations in trend or shape of curve are noted, these could be an indication of injury and impairment that would contraindicate return to work.

5.5 Limitations

There are some limitations that should delimit interpretation of the study results. Primarily, the protocol included simulated Functional Capacity Evaluation tasks performed in a biomechanics laboratory setting. Procedures attempted to stay as true to the clinical procedures as possible but it is possible that performance could have been affected by the environment. Along this line, motivation to perform could have been a factor, but likely only for the capacity performance (Corbett, Barwood, Ouzounoglou, Thelwell, & Dicks, 2012). Further, task instructions were given by a graduate student, not a trained FCE administrator, which could affect task performance or outcomes (Matheson L. , et al., 1992; Fasoli, Trombly, Tickle-Degnen, & Verfaellie, 2002).

It should also be noted that while the purpose of this study was to create normative kinematic profiles from a young, healthy population, the majority of the participants in this study were students or had office jobs. A population of the same age but in a different occupation category could have different strategies to complete these tasks due to task familiarity (Faber, Kingma, & van Dieen, 2011).

Although these tasks were chosen to evaluate upper limb abilities, neck kinematics could also provide insight into compensations from fatigue or injury (Tsang, Szeto, & Lee, 2014; Szeto, Straker, & O'Sullivan, 2005). However, neck motion was not examined in this current study and therefore some kinematics pertinent to identifying compensations may not be included in this dataset.

There are some protocol and processing limitations of this study. Participants were given clear instructions for each task, but in attempt to reduce the constraints on movement, not all movements or postures were controlled. Specifically, the strategy to hold the crate during the waist to overhead lift was not controlled and as such, participants used a variety of strategies. In addition, full body translation was not constrained during the overhead work task, so some participants could have moved their whole body forward in order to bring the load closer to the body (Anton, et al., 2001). Differences between normative profiles were determined through t tests and ANOVAs run on discrete variables. It is possible this is not entirely reflective of differences, or lack thereof, between the profiles and other strategies, such as principal component analysis, could have had different results (Deluzio, Harrison, Coffey, & Caldwell, 2014). Finally, it is possible that there could be differences in motion within a cycle, particularly comparing the first half of the cycle to the second half of the cycle. Future studies should partition the cycles based on direction to determine if there are changes in strategy dependent on direction.

The data is very sensitive to the specific set up of these tasks. However, because these are FCE tasks, future performance of these tasks would always closely match the set up and protocol of the current investigation, as this is standard for FCEs (Lafayette Instrument, 2002; Lafayette Instrument, 1999; Reneman, Soer, & Gerrits, Basis for an FCE methodology for patients with work-related upper limb disorders, 2005). In fact, to ensure validity and reliability of FCE results, which is of utmost important for FCEs used in worker's compensation cases, the protocol and set up of FCEs should remain as consistent as possible (Brouwer, et al., 2003).

Finally, there is an issue of applying mean population data to individual performance. While it is suggested that if a patient uses postures or movement strategies that are outside one standard deviation of the mean, high risk exists or the activity is potentially "unsafe". However, it is possible that different strategies are still "safe" or healthy. Therefore, when using this information and profiles provided in this study, evaluators are still encouraged to think critically about the implications of an individual's movement strategies.

5.6 Future Directions

To investigate the potential clinical usefulness of the healthy population kinematic profiles, an identical study protocol should be repeated to study the movements of a diagnosed injured population. A population with a pathological shoulder would likely demonstrate deviations from these kinematic profiles but the direction and size of the deviation would depend on the specific injury. For instance, patients with a rotator cuff injury, such as a supraspinatus tear or impingement, would likely avoid abducted and internally rotated humeral postures exhibited in many of the tasks (Brossmann, et al., 1996) and subsequently alter trunk or elbow motion to compensate (Coté, Raymond, Mathieu, Feldman, & Levin, 2005; Lomond & Cote, 2011a). The current results provide a robust basis for making these comparisons.

Based on the results from the comparisons between healthy and injured populations, observation criteria or cues could be developed for improved guidelines for evaluators. By analyzing control and pathological populations, the important kinematic changes and characteristic motions can be identified and used to direct creation of guidelines.

The ability of evaluators or clinicians to classify postures and distinguish differences when using the kinematic profiles and future guidelines for guidance should also be investigated, either through video based assessment or observation assessment concurrent with kinematic data collection (Smith, 1994). Further, it would be of interest to test if there is an association between degree of dyskinesis and posture category assigned by an experienced FCE evaluator (Bernhardt, Bate, & Matyas, 1998).

Further investigation into other quantitative variables could also provide insight into measured differences between healthy and injured groups. Interjoint coordination and coefficient variation have been used to quantify differences between groups (Coté, Raymond, Mathieu, Feldman, & Levin, 2005; Lindbeck & Kjellberg, 2001; Andriacchi & Dyrby, 2005) and could provide useful information for FCE task performance of the control and pathological populations. In addition, the normative kinematic profiles created in this investigation seem to be consistent with the theory that human movement trajectories are planned based on minimal metabolic cost, through maximum smoothness, or minimum jerkiness (Alexander, 1997; Flanagan & Ostry, 1990). It is possible, then, that injured populations would not show the same trajectory or smoothness and this could be apparent in jerk. Jerk, or movement smoothness, could be a measure of interest for identifying differences between healthy or injured populations in future investigations.

Finally, further work into the kinetic changes that result from both the normal compensations to increasing intensity and potential compensations exhibited by pathological populations would provide insight to the implications of the changes. Certain modifications to movement strategies to fatigue or injury may occur in attempt to decrease load on injured joints (Coté, Raymond, Mathieu, Feldman, & Levin, 2005) or prevent overloading of muscles (Jensen, Laursen, & Sjogaard, 2000). The current study provides evidence of changes resulting from increasing intensity but also identifies the need for continued research into the effects of kinematic alterations.

Chapter 6: Clinical Relevance and Conclusions

The primary contribution of this investigation was to quantitatively examine and characterize the kinematics of a young, healthy population during upper extremity focused Function Capacity Evaluation (FCE) tasks. These data provide guidance for understanding and identifying healthy or normal movement during these tasks that has not yet been provided to evaluators. In fact, current guidelines encourage FCE evaluators to watch for changes from normal postures or movement strategies (Trippolini, et al., 2014a), but normal posture has yet to be defined to allow for these comparisons. This thesis provides key knowledge to fill this gap in FCE observation analysis. In addition, these data identify kinematic changes that occur in a healthy population that are caused by task factors, specifically increasing intensity in a waist to overhead lift task and overhead task, that can be observed by evaluators and subsequently used to stop the test and direct treatment or return to work modifications.

The most important outcome of this investigation is the comprehensive dataset of upper limb and torso kinematics in these FCE tasks. Because these tasks are simulations of work tasks with the purpose to evaluate motions relevant to common work tasks, these data can be used in both clinical and ergonomic settings to assess patient or worker movement and postures.

The results of this study also indicate that little benefit can be derived by evaluating males and females using different normative profiles or guidelines in these tasks. However, in tasks that are not scaled to body size, sex may influence useful interpretation of task performance. This investigation also supports the use of the kinesiophysical approach in FCE assessment. Visible changes in kinematics and segment velocities occur as participants reach maximum capacity allowing evaluators to more consistently identify changes in effort and movement compensations. Several angles changed by at least 5°, confirming the clinical relevance of the changes and the likelihood that evaluators will have the ability to see and interpret the deviations that occur (Ebaugh, McClure, & Karduna, 2005; Ludewig & Cook, 2000; van Wyk, Weir, Andrews, Fielder, & Callaghan, 2009).

The kinematics of these tasks indicate their utility as evaluation tools for assessing the upper limb, and specifically of the shoulder and wrist, as the highest demand postures and largest range of motion are required in these areas. It is likely that injured patients will exhibit kinematics or movement strategies different from the healthy control group that can be more consistently identified through comparison to the normative data.

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Appendix A: Disability of Arm, Shoulder and Hand (QuickDASH) Questionnaire

THE QuickDASH

OUTCOME MEASURE

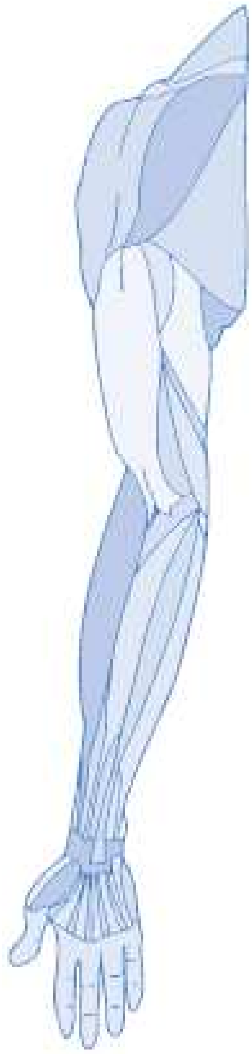
INSTRUCTIONS

This questionnaire asks about your symptoms as well as your ability to perform certain activities.

Please answer *every question*, based on your condition in the last week, by circling the appropriate number.

If you did not have the opportunity to perform an activity in the past week, please make your *best estimate* of which response would be the most accurate.

It doesn't matter which hand or arm you use to perform the activity; please answer based on your ability regardless of how you perform the task.



*Quick*DASH

Please rate your ability to do the following activities in the last week by circling the number below the appropriate response.

	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	UNABLE
1. Open a tight or new jar.	1	2	3	4	5
2. Do heavy household chores (e.g., wash walls, floors).	1	2	3	4	5
3. Carry a shopping bag or briefcase.	1	2	3	4	5
4. Wash your back.	1	2	3	4	5
5. Use a knife to cut food.	1	2	3	4	5
6. Recreational activities in which you take some force or impact through your arm, shoulder or hand (e.g., golf, hammering, tennis, etc.).	1	2	3	4	5

	NOT AT ALL	SLIGHTLY	MODERATELY	QUITE A BIT	EXTREMELY
7. During the past week, *to what extent* has your arm, shoulder or hand problem interfered with your normal social activities with family, friends, neighbours or groups?	1	2	3	4	5

	NOT LIMITED AT ALL	SLIGHTLY LIMITED	MODERATELY LIMITED	VERY LIMITED	UNABLE
8. During the past week, were you limited in your work or other regular daily activities as a result of your arm, shoulder or hand problem?	1	2	3	4	5

Please rate the severity of the following symptoms in the last week. *(circle number)*	NONE	MILD	MODERATE	SEVERE	EXTREME
9. Arm, shoulder or hand pain.	1	2	3	4	5
10. Tingling (pins and needles) in your arm, shoulder or hand.	1	2	3	4	5

	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	SO MUCH DIFFICULTY THAT I CAN'T SLEEP
11. During the past week, how much difficulty have you had sleeping because of the pain in your arm, shoulder or hand? *(circle number)*	1	2	3	4	5

***Quick*DASH DISABILITY/SYMPTOM SCORE** = $\left(\left[\frac{\text{sum of n responses}}{n}\right] - 1\right)$ x 25, where n is equal to the number of completed responses.

A *Quick*DASH score may <u>not</u> be calculated if there is greater than 1 missing item.

*Quick*DASH

WORK MODULE (OPTIONAL)

The following questions ask about the impact of your arm, shoulder or hand problem on your ability to work (including homemaking if that is your main work role).

Please indicate what your job/work is:____

❐ I do not work. (You may skip this section.)

Please circle the number that best describes your physical ability in the past week.

Did you have any difficulty:	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	UNABLE
1. using your usual technique for your work?	1	2	3	4	5
2. doing your usual work because of arm, shoulder or hand pain?	1	2	3	4	5
3. doing your work as well as you would like?	1	2	3	4	5
4. spending your usual amount of time doing your work?	1	2	3	4	5

SPORTS/PERFORMING ARTS MODULE (OPTIONAL)

The following questions relate to the impact of your arm, shoulder or hand problem on playing *your musical instrument or sport or both*. If you play more than one sport or instrument (or play both), please answer with respect to that activity which is most important to you.

Please indicate the sport or instrument which is most important to you:____________________________

❑ I do not play a sport or an instrument. (You may skip this section.)

Please circle the number that best describes your physical ability in the past week.

Did you have any difficulty:	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	UNABLE
1. using your usual technique for playing your instrument or sport?	1	2	3	4	5
2. playing your musical instrument or sport because of arm, shoulder or hand pain?	1	2	3	4	5
3. playing your musical instrument or sport as well as you would like?	1	2	3	4	5
4. spending your usual amount of time practising or playing your instrument or sport?	1	2	3	4	5

SCORING THE OPTIONAL MODULES: Add up assigned values for each response; divide by 4 (number of items); subtract 1; multiply by 25.
An optional module score may <u>not</u> be calculated if there are any missing items.

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Appendix B: Physical Activity Readiness Questionnaire (PAR-Q)

Physical Activity Readiness
Questionnaire - PAR-Q
(revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

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

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

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

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

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

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

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

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

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

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

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

NAME ________________________________

SIGNATURE ________________________________ DATE ________________________

SIGNATURE OF PARENT
or GUARDIAN (for participants under the age of majority) ________________________ WITNESS ________________________

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

 Supported by: Health Canada Santé Canada

continued on other side...

Appendix C: Modified Borg Ratings of Perceived Exertion Scale (CR-10)

0 Nothing at all	
0.5 Very, very weak	(just noticeable)
1 Very weak	
2 Weak	(light)
3 Moderate	
4 Somewhat strong	
5 Strong	(heavy)
6	
7 Very strong	
8	
9	
10 Very, very strong	(almost maximal)

- Maximal

Appendix D: Fingertip Dexterity (Purdue Pegboard) Verbal Instructions

General Instructions

The subject should be comfortably seated at the testing table directly in front of the Purdue Pegboard, which is placed on the table with the row of cups (Under the nameplate) at the top of the board. The far right and far left cups should have 25 pins in each to equal a total of 50 pins. For right-handed subjects, the cup to the right of center should have 40 washers. If the subject is left-handed, the collar and washer locations should be on the reverse side of center. The following directions are for single subject testing and should be appropriately modified for group testing.

When the subject(s) is seated and ready to begin, say:

"This is a test to see how quickly and accurately you can work with your hands. Before you begin each battery of the test, you will be told what to do and then you will have an opportunity to practice. Be sure you understand exactly what to do."

Right Hand (30 seconds)

Begin by saying and demonstrating:

"Pick up one pin at a time with your right hand from the right-handed cup. Starting with the top hole, place each pin in the right-handed row. (Leave the pin used for demonstration in the hole.) Now you may insert a few pins for practice. If during the testing time you drop a pin, do not stop to pick it up. Simply continue by picking another pin out of the cup."

Correct any errors made in placing the pins and answer any questions. When the subject has inserted three or four pins and appears to understand the operation, say:

"Stop. Now take out the practice pins and put them back into the right-handed cup."

After the subject completes this task, say:

"When I say 'Begin,' place as many pins as possible in the right-handed row, starting with the top hole. Work as rapidly as you can until I say 'Stop.'"

"Are you ready? Begin."

Start timing when you say "Begin." At the end of exactly 30 seconds, say:

"Stop."

Count the number of pins inserted and record the Right Hand score. This is the total number of pins the subject placed with the right hand. Leave the pins in the holes.

Left Hand (30 seconds)

Begin by saying:

"Pick up one pin at a time with your left hand from the left-handed cup. Place each pin in the left-handed row, starting with the top hole. You may insert a few pins for practice

When the subject has inserted three or four pins and appears to understand the operation, say:
"Stop. Now take out the practice pins, and put them back into the left-handed cup."

After the subject completes this task, say:
"When I say 'Begin,' place as many pins as possible in the left-handed row, starting with the top hole. Work as rapidly as you can until I say 'Stop.'"
"Are you ready? Begin."

Start timing exactly when you say "Begin." At the end of exactly 30 seconds, say:
"Stop."

Count the number of pins inserted and record the Left-Hand score. This is the total number of pins the subject placed with the left hand. Leave the pins in the holes. After the Right Hand and Left-Hand test batteries have been completed, the subject returns all pins to their proper cups.

Both Hands (30 seconds)

This test battery tests both hands working together. Begin by saying:
"For this part of the test, you will use both hands at the same time. Pick up a pin from the right-handed cup with your right hand, and at the same time pick up a pin from the left-handed cup with your left hand. Then place the pins down the rows. Begin with the top hole of both rows. (Demonstrate. Then replace the pins used for demonstration.) **Now you may insert a few pins with both hands for practice."**

After the subject has three of four pairs of practice pins correctly inserted, say:
"Stop. Take out the practice pins, and put them back in their cups."

Then say:
"When I say 'Begin,' place as many pins as possible with both hands, starting with the top hole of both rows. Work as rapidly as you can, until I say 'Stop.'"
"Are you ready? Begin."

Start timing when you say "Begin." At the end of exactly 30 seconds, say
"Stop."

Count the number of pairs of pins inserted (not the total number of pins), and record the score. The subject then returns the pins to the proper cups.

Right + Left + Both (Sum of scores)

This score is not based on a separate test; it is obtained from combining the test scores of the previous three test batteries. Add the scores recorder for Right Hand, Left Hand, and Both Hands; this is the score that you record for R + L + Both.
This score does not have to be recorded during the actual testing period. The Assembly test may begin immediately after the Both Hands score is recorded.

Assembly (1 minute)

This test battery consists of assembling pins, collars, and washers. Demonstrate the following operations while saying:

"Pick up one pin from the right-handed cup with your right hand. While you are placing it in the top hole in the right-handed row, pick up a washer with your left hand. As soon as the pin has been placed, drop the washer over the pin. While the washer is being placed over the pin with you left hand, pick up a collar with your right hand. While the collar is being dropped over the pin, pick up another washer with your left hand and drop it over the collar. This completes the first 'assembly,' consisting of a pin, a washer, a collar, and a washer. While the final washer for the first assembly is being placed with your left hand, start the second assembly immediately by picking up another pin with your right hand. Place it in the next hole; drop a washer over it with your left hand, and so on, completing another assembly. Now take a moment to try a few practice assemblies."

Emphasize that both hands should be operating at all times: one picking up a pin, one a washer, one a collar, and so on. The subject should be allowed to make four or five complete assemblies before the test is begun to make certain the subject fully understands the "alternating" procedure. The subject must keep both hands moving at the same time. If he or she fails to do this, the administrator should give further instructions.

After the subject has practiced the assemblies say:

"Stop. Now return the pins, collars, and washers to their proper cups."

Then say:

"When I say 'Begin,' make as many assemblies as possible, beginning with the top hole. Work quickly until I say 'Stop.'"

Start timing when you say "Begin." After exactly 1 minute (60 seconds), say:

"Stop."

Count the number of parts assembled and record the Assembly score. Since there are four parts in each assembly, if the subject made eight complete assemblies, the score is 8 multiplied by 4 (parts), or 32. Beyond completed assemblies, if there are additional parts properly placed at the end of the minute, they are also added to the Assembly score. For example, if there is another pin and first washer in addition to those 2 parts, the score is 32 + 2, or 34. After the test administrator records this score, the subject should return the pins, collars, and washers to the proper cup

Appendix E: Hand and Forearm Dexterity (Minnesota Manual Dexterity) Verbal Instructions

Placing Test

Starting Position. Put the board on the table about 10 inches from the edge. Insert the disks into the holes in the board. Lift the board UP, allowing the disks to fall through the holes and remain in straight rows and columns on the table. Now place the board directly in front of the disks. **Note: If the disks moved out of place, manually realign the disks.** The board should now be about 1 inch from the edge of the table closest to the subject. This is the starting position for the placing test.

Begin by saying and demonstrating:
"The object of this test is to see how fast you can put the disks into the holes of the board using only one hand. You will want to use your dominant hand."

Demonstrate as you read the following instructions.
Note: If you are facing the subject across the board, remember to demonstrate on your LEFT because the instructions pertain to the subject's RIGHT. Also remember that TOP to the subject is BOTTOM to you. You should start your demonstration slowly and increase speed as you speak.
"You must begin on your RIGHT. Pick up the bottom disk and insert it into the top hole of the board. Now, you must pick up the next disk in the column on the right, and so on. You will move from right to left on this test. Once you complete one column, repeat the previous sequence in the second column until you have filled the entire board."

Continue demonstrating until two columns have been filled. Now, remove the eight disks from the board and put them back into place above the board.
Note: You may have to use a ruler or an object with a straight edge to align the disks properly.
"You may hold the board with your free hand if you wish to do so. Do you remember the order in which you pick up the disks and place them down?"

If the instructions must be repeated, point to the disks in the order that they should be picked up and then point to the disks in the order that they should be placed into the holes in the board.
"You must make sure that all of the disks are fully inserted into the holes of the board before the trial is complete. If you dropped a disk, you must pick it up and insert it into the proper hole before the time is stopped. Your score will be the total number of seconds it takes to complete several trials. We will record the time for each trial separately. When you finish one trial, we must rearrange the board and disks into the starting position before starting another trial. Please do not touch the disks until you hear further instruction."

Start the stopwatch or log the time as soon as you say the word, "GO." During the practice trial, you can provide assistance to the subject if necessary.
You will now begin the first trial by saying:
"Put your hand on the first disk. READY, GO!"

When the subject is finished with the trial, log the time in seconds in the space provided on the scoresheet. Now, you must move the board (now filled with disks) to the top. Lift the board UP, allowing the disks to fall through the holes. Now place the board directly in front of the disks. **Remember: The board should be about on 1 inch from the edge of the table.** The board should now be in the starting position for the next trial of the Placing Test. You can begin the next trial by saying:
"Put your hand on the first disk. READY, GO!"

Repeat the above procedure until all of the desired trials are completed. You should encourage the subject between every trial by stating the appropriate sentence:
"Remember, you are being timed, so complete each trial as quickly as possible."
Or,
"You did a good job, but I believe that you can complete the next trial faster."
And on the last trial,
"This is the last trial and should be your best time."

At the end of the last trial, you will say:
"That's all for this test."
If you are going to give another test, you should let your subject know that he or she will be taking a different test now. At the completion of the Placing Test, the board and disks should be in the correct starting position for the Turning Test.

Turning Test

Starting Position: Put the board on the table about1 inch from the edge closest to the subject. Insert all of the disks into the holes in the board with either the RED or BLACK side facing UP (the color must be consistent on the whole board). You should now be in the starting position for the Turning Test.

Begin by saying:
"The object of this test is to see how fast you can pick up the disks with one hand, turn them with the other hand, and replace the disks back into the holes on the board."

You should start your demonstration slowly and increase speed as you speak. Figure 3 illustrates the sequence of rows and the direction of travel in the Turning Test. **Note: If you are facing the subject across the board, remember to demonstrate on your LEFT because the instructions pertain to the subject's RIGHT. Also remember that TOP to the subject is BOTTOM to you.** Demonstrate as you read the following instructions.
"With your LEFT hand, pick up the block from the upper right-hand corner. Turn the disk while passing it to your RIGHT hand and return it into the original hole in the board with the BOTTOM side facing UP. You must work to your LEFT across the board on the top row."

Continue to demonstrate until you complete the entire TOP row. As you start to demonstrate the second row, say:
"Now with your RIGHT hand, pick up the first block in the second row. Turn the disk while passing it to your LEFT hand and return it into the original hole with the BOTTOM side facing UP. You will work to your RIGHT until you complete the entire row."

The subject always picks UP the blocks with the hand that LEADS and put them DOWN with the hand that FOLLOWS. Continue demonstrating the test in its entirety.
"As you work back to the LEFT in the third row, you will use your LEFT hand to pick up the disk and your RIGHT hand to return it back to the original hole. Working back to your RIGHT on the fourth row, you must use your RIGHT hand to pick up the disk and your LEFT hand to return it."

You should finish the test at a moderate speed. All of the disks must be turned so the same color is facing UP. The board should now be in the original starting position.
"You must make sure that all of the disks are fully inserted into the holes of the board before the trial is complete. If you dropped a disk, you must pick it up and insert it into the proper hole before the time is stopped. Your score will be the total number of seconds it takes to complete several trials. We will record the time for each trial separately. When you finish one trial, the board and disks should already be in the starting position for another trial. In other words, the opposite color on the disks is now exposed. Please do not touch the disks until you hear further instructions."

Start the stopwatch or note the time as soon as you say the word, "GO." During the practice trial, you can provide assistance to the subject if necessary.
You will now begin the first trial by saying:
"Put your LEFT hand on the disk in the top right hand corner of the board. READY, GO!"

When the subject is finished with the trial, log the time in seconds in the space provided on the scoresheet. **Remember: The board should be about 1inch from the edge of the table. You can begin the next trial by saying:**
"Put your LEFT hand on the disk in the top right hand corner. READY, GO!"

Repeat the above procedure until all of the desired trials are completed. You should encourage the subject between every trial by stating the appropriate sentence:
"Remember, you are being timed, so complete each trial as quickly as possible."
Or,
"You did a good job, but I believe that you can complete the next trial faster."
And on the last trial,
"This is the last trial and should be your best time."

At the end of the last trial, you will say:
"That's all for this test."
You have now completed the last test battery of the MMDT.

Appendix F: Kinematic Profiles for Functional Capacity Evaluation Tasks

Joint	Angle	Direction
Torso	Extension Flexion	Positive Negative
	Right Lateral Flexion Left Lateral Flexion	Positive Negative
	Left Axial Rotation Right Axial Rotation	Positive Negative
Humerothoracic	Abduction Adduction	Positive Negative
	Flexion Extension	Positive Negative
	Internal Rotation External Rotation	Positive Negative
Elbow	Flexion Hyperextension	Positive Negative
	Pronation Supination	Positive Zero
Wrist	Flexion Extension	Positive Negative
	Ulnar Deviation Radial Deviation	Positive Negative

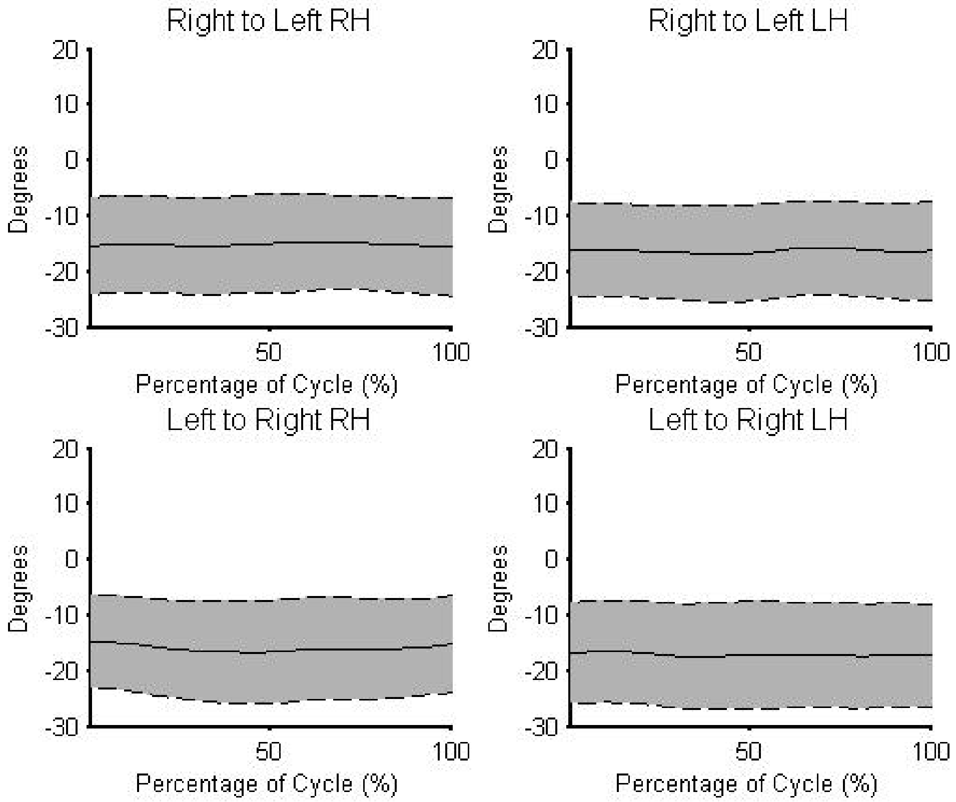


Figure D1: Mean torso +extension/-flexion kinematic profiles, with +/- one standard deviation, for the Repetitive Reaching task.

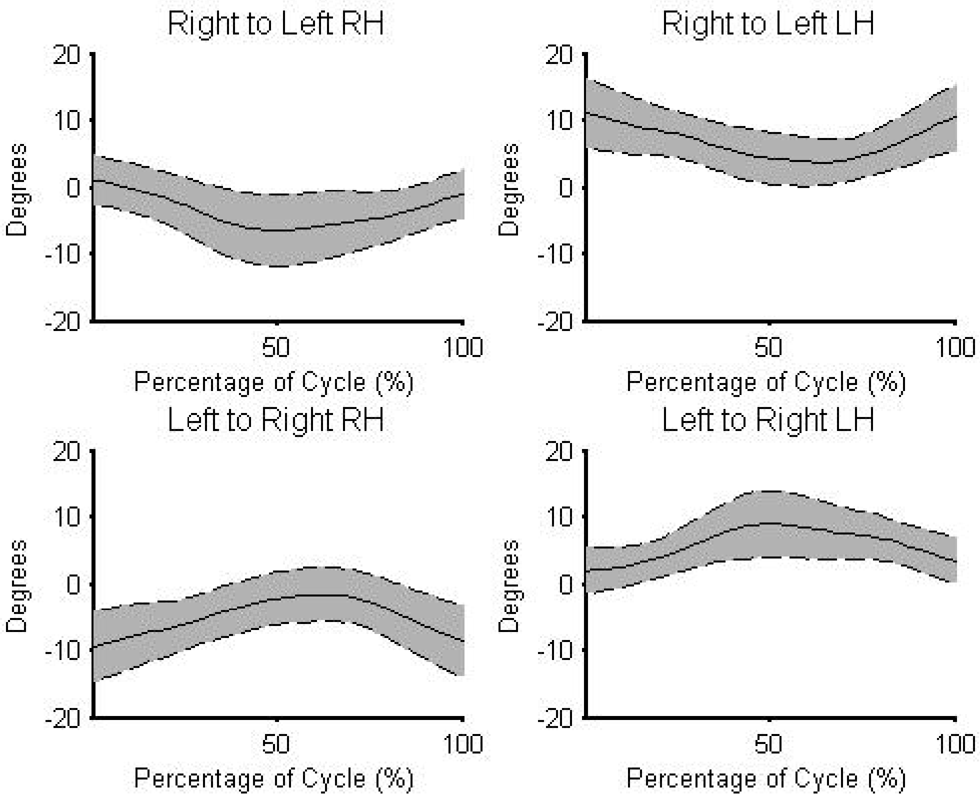


Figure D2: Mean torso +right/-left lateral flexion kinematic profiles, with +/- one standard deviation, for the Repetitive Reaching task.

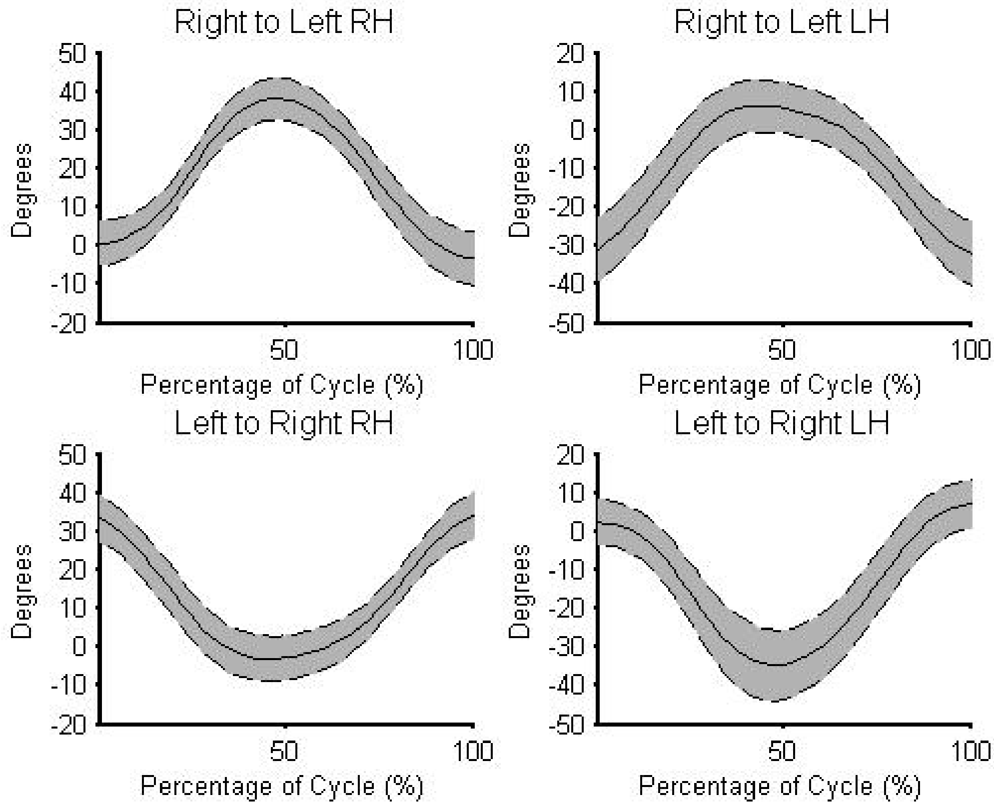


Figure D3: Mean torso +left/-right axial rotation kinematic profiles, with +/- one standard deviation, for the Repetitive Reaching task.

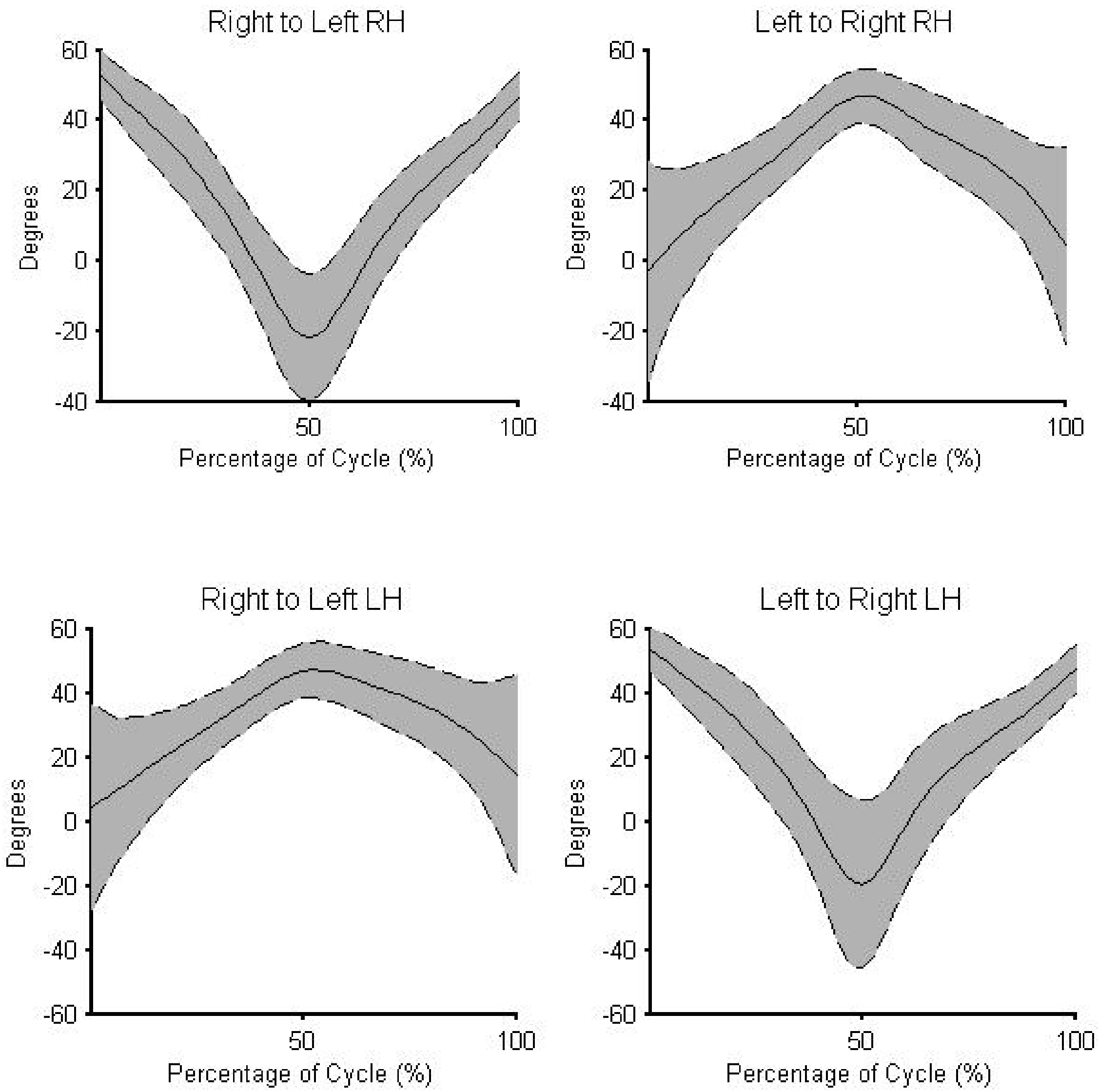


Figure D4: Mean right (top) and left (bottom) thoracohumeral +abduction/-adduction kinematic profiles, with +/- one standard deviation, for the Repetitive Reaching task.

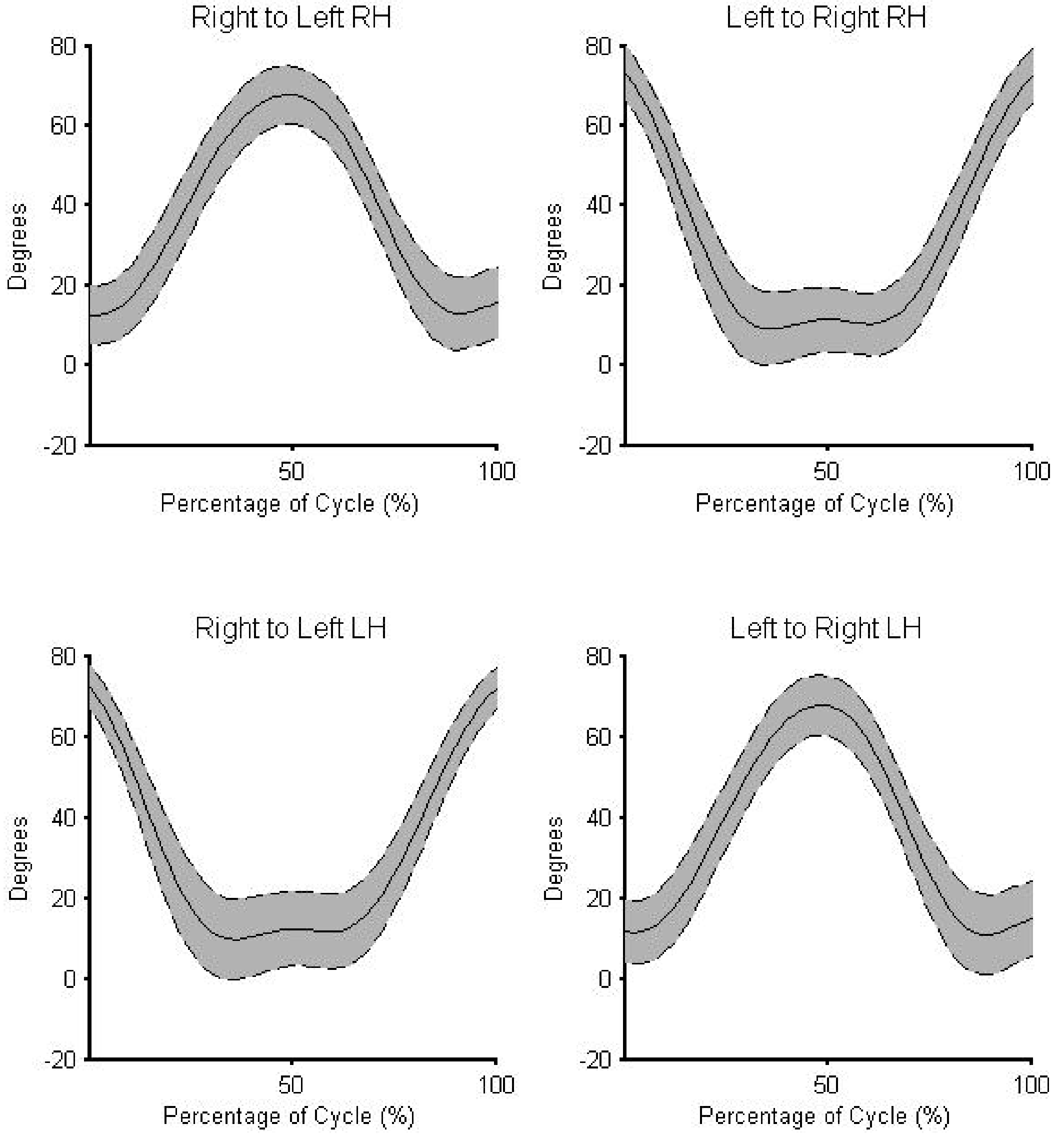


Figure D5: Mean right (top) and left (bottom) thoracohumeral +flexion/-extension kinematic profiles, with +/- one standard deviation, for the Repetitive Reaching task.

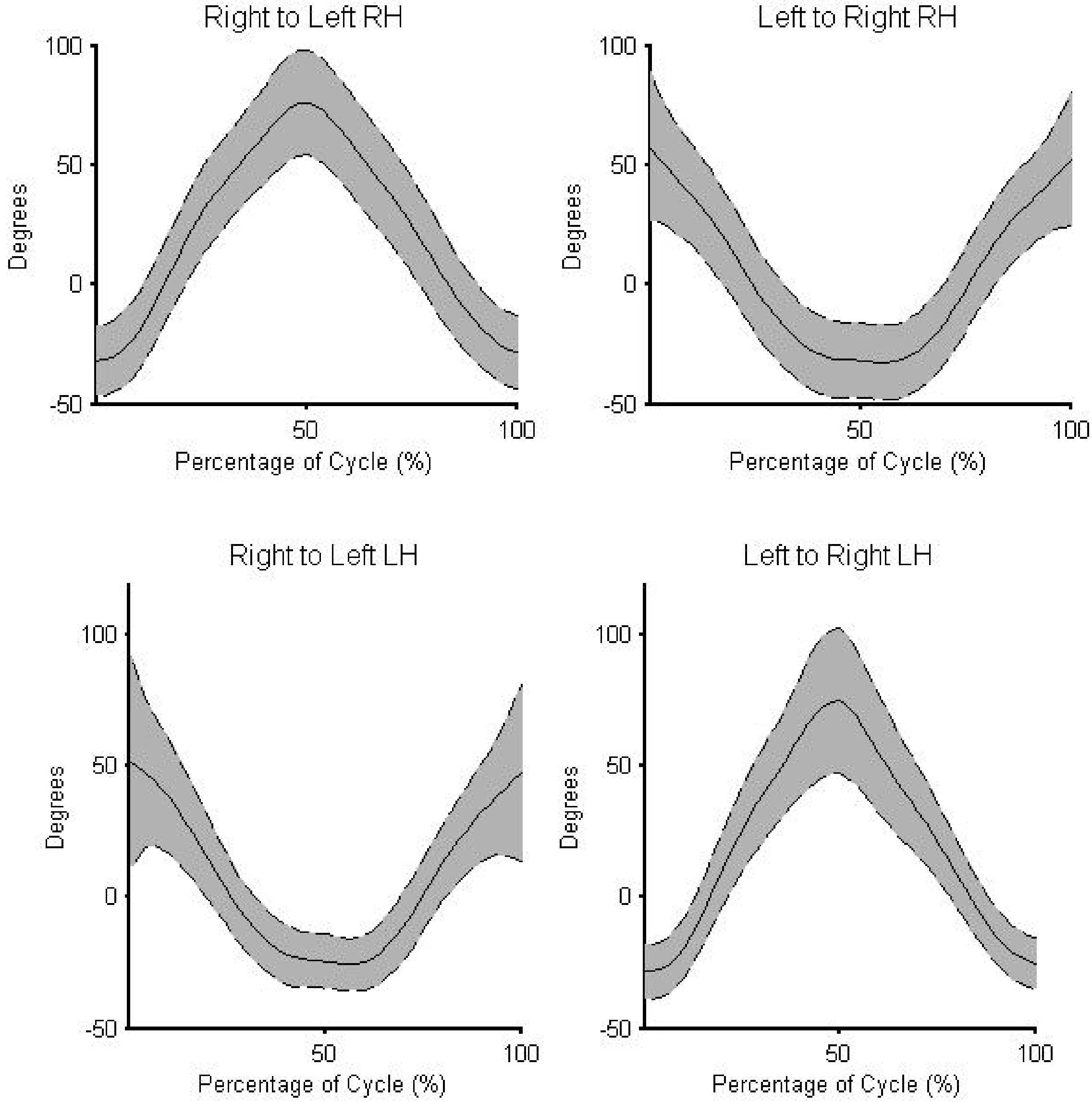


Figure D6: Mean right (top) and left (bottom)thoracohumeral +internal/-external axial rotation kinematic profiles, with +/- one standard deviation, for the Repetitive Reaching task.

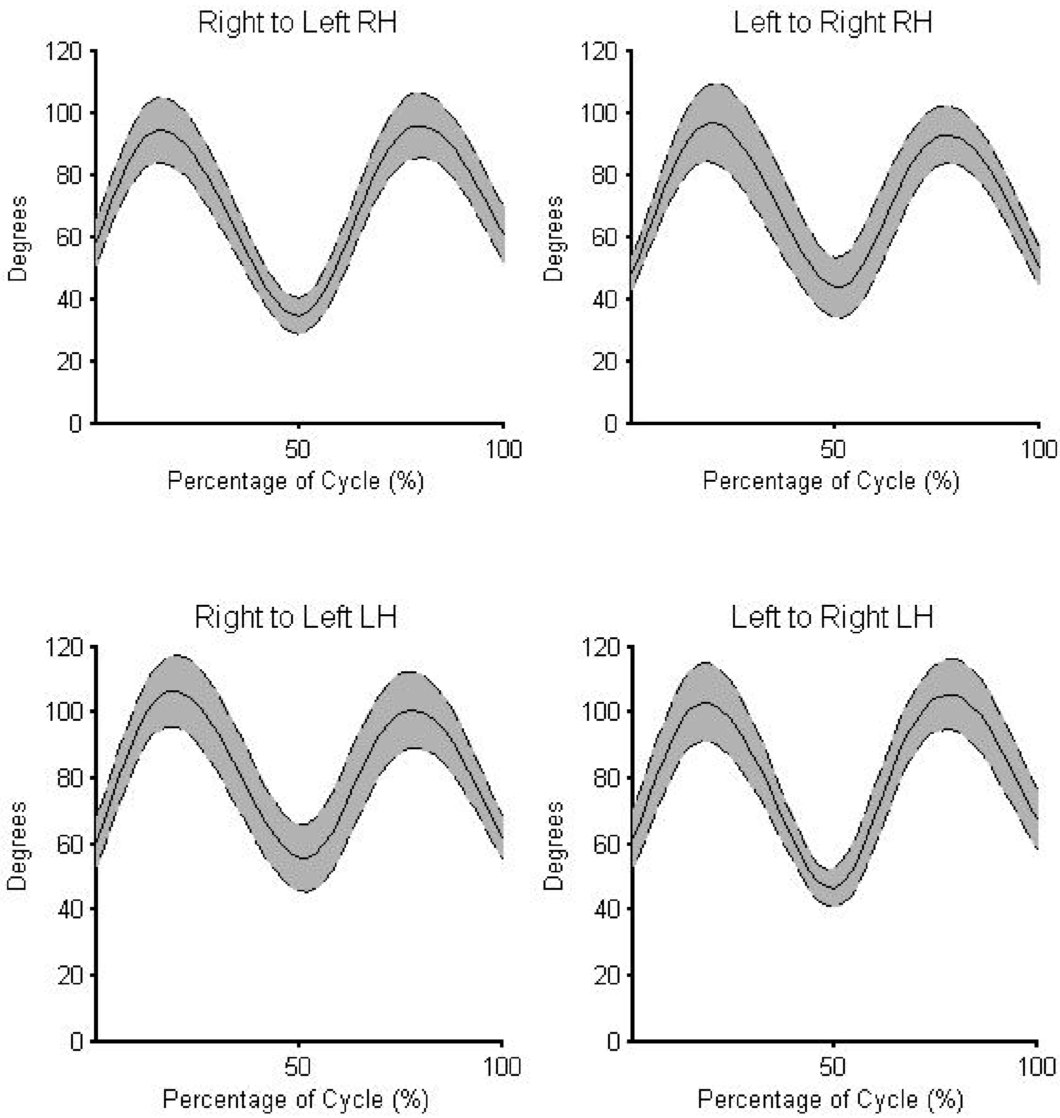


Figure D7: Mean right (top) and left (bottom) elbow +flexion/-hyperextension kinematic profiles, with +/- one standard deviation, for the Repetitive Reaching task.

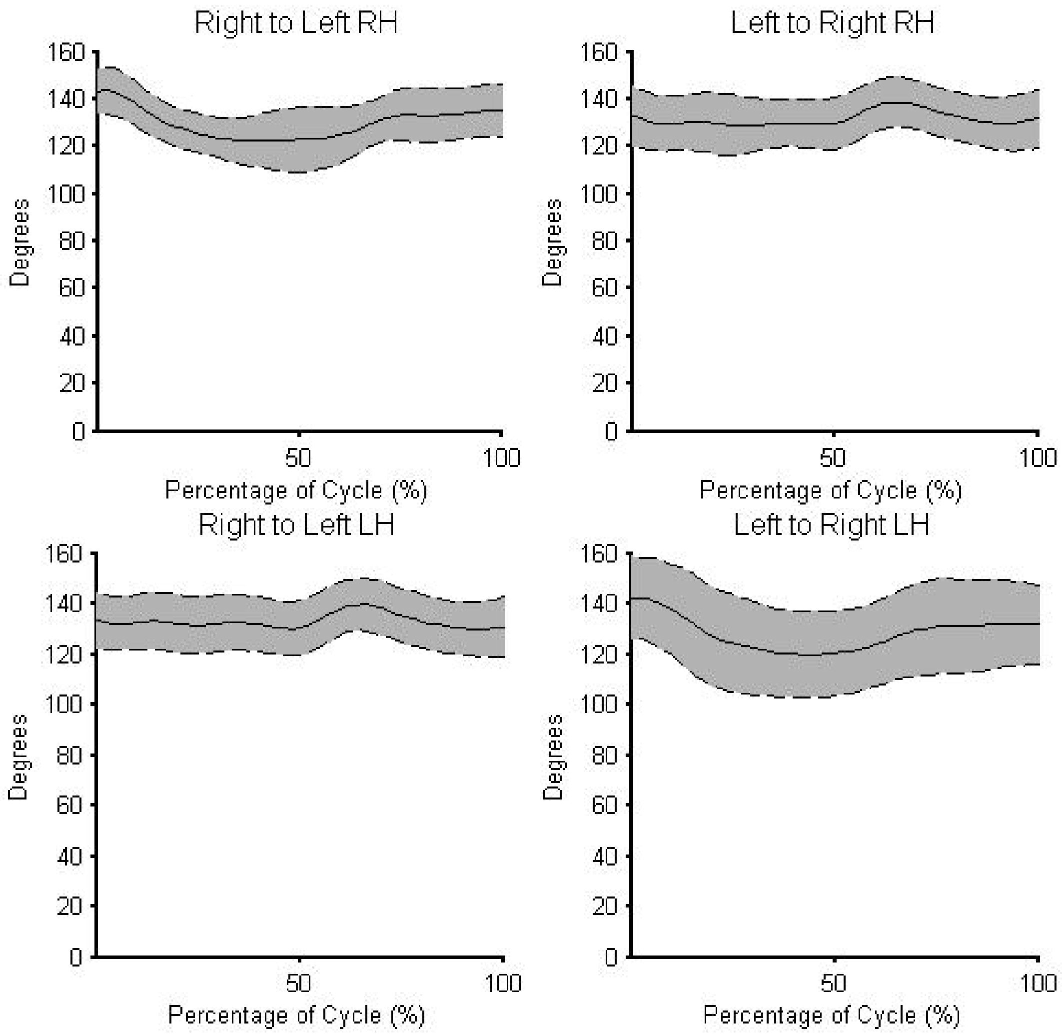


Figure D8: Mean right (top) and left (bottom) elbow pronation kinematic profiles, with +/- one standard deviation, for the Repetitive Reaching task.

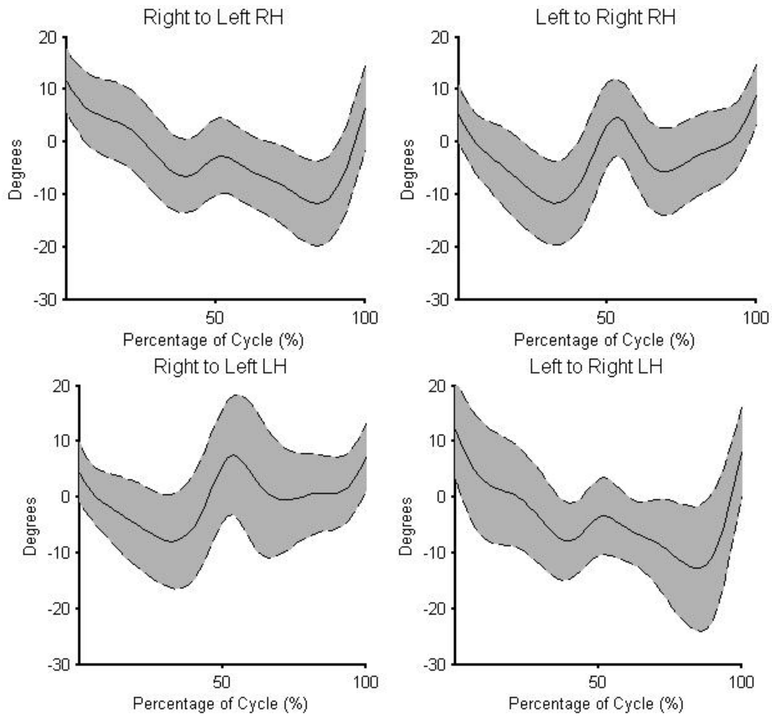


Figure D9: Mean right (top) and left (bottom) wrist +flexion/-extension kinematic profiles, with +/- one standard deviation, for the Repetitive Reaching task.

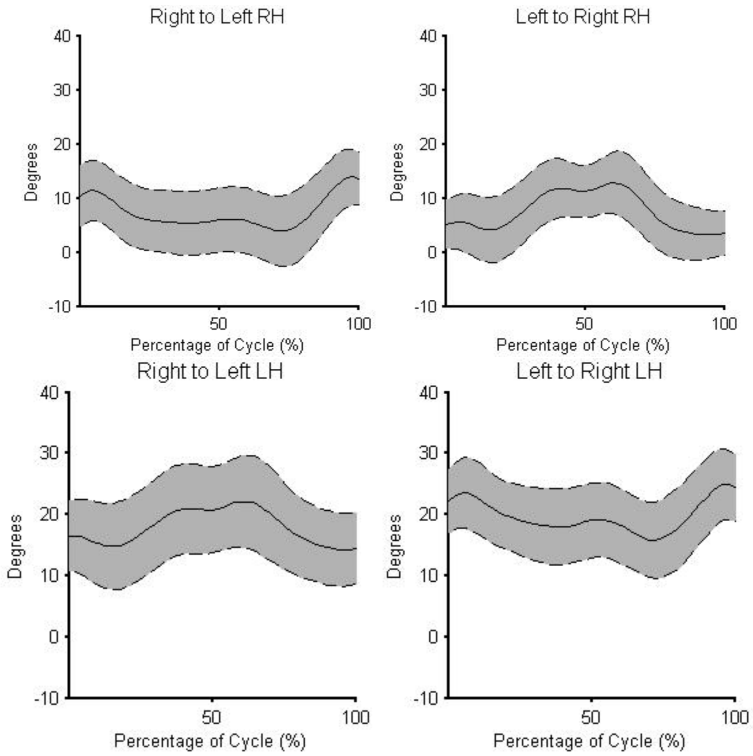


Figure D10: Mean right (top) and left (bottom) wrist +ulnar/-radial deviation kinematic profiles, with +/- one standard deviation, for the Repetitive Reaching task.

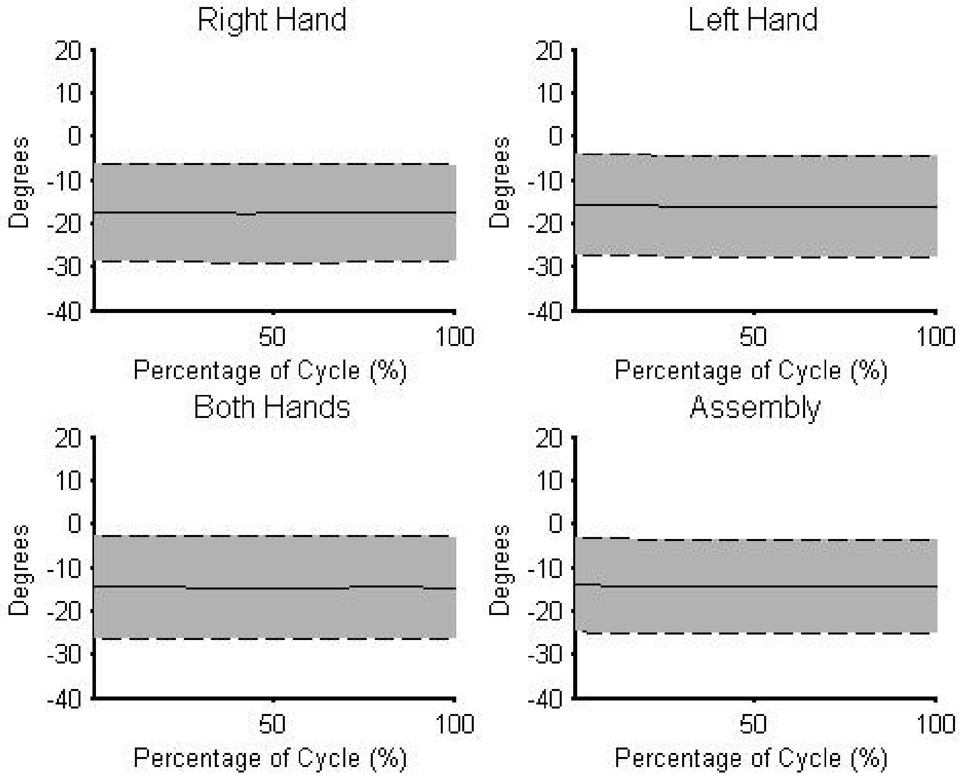


Figure D11: Mean torso +extension/-flexion kinematic profiles, with +/- one standard deviation, for the Fingertip Dexterity task.

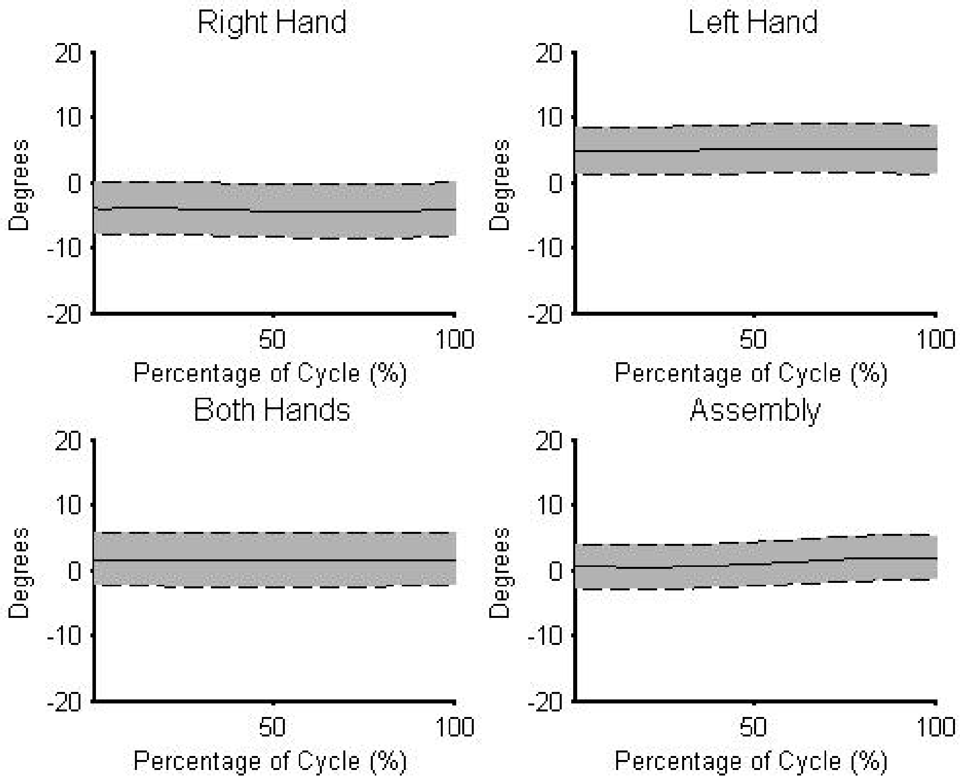


Figure D12: Mean torso +right/-left kinematic profiles, with +/- one standard deviation, for the Fingertip Dexterity task.

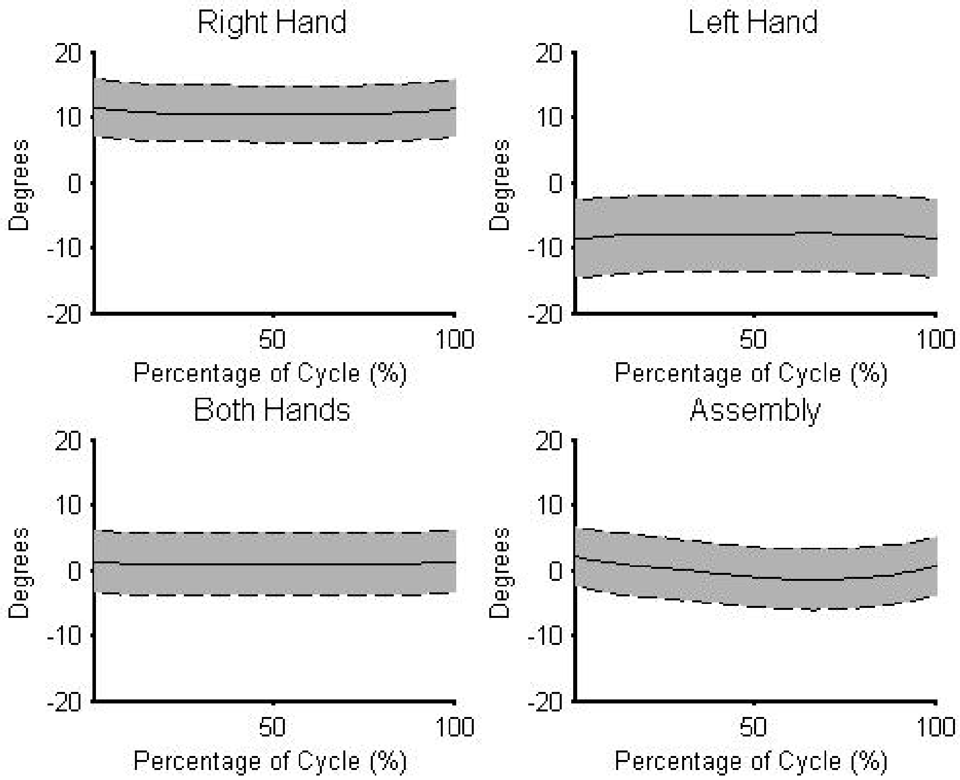


Figure D13: Mean torso +left/-right axial rotation kinematic profiles, with +/- one standard deviation, for the Fingertip Dexterity task.

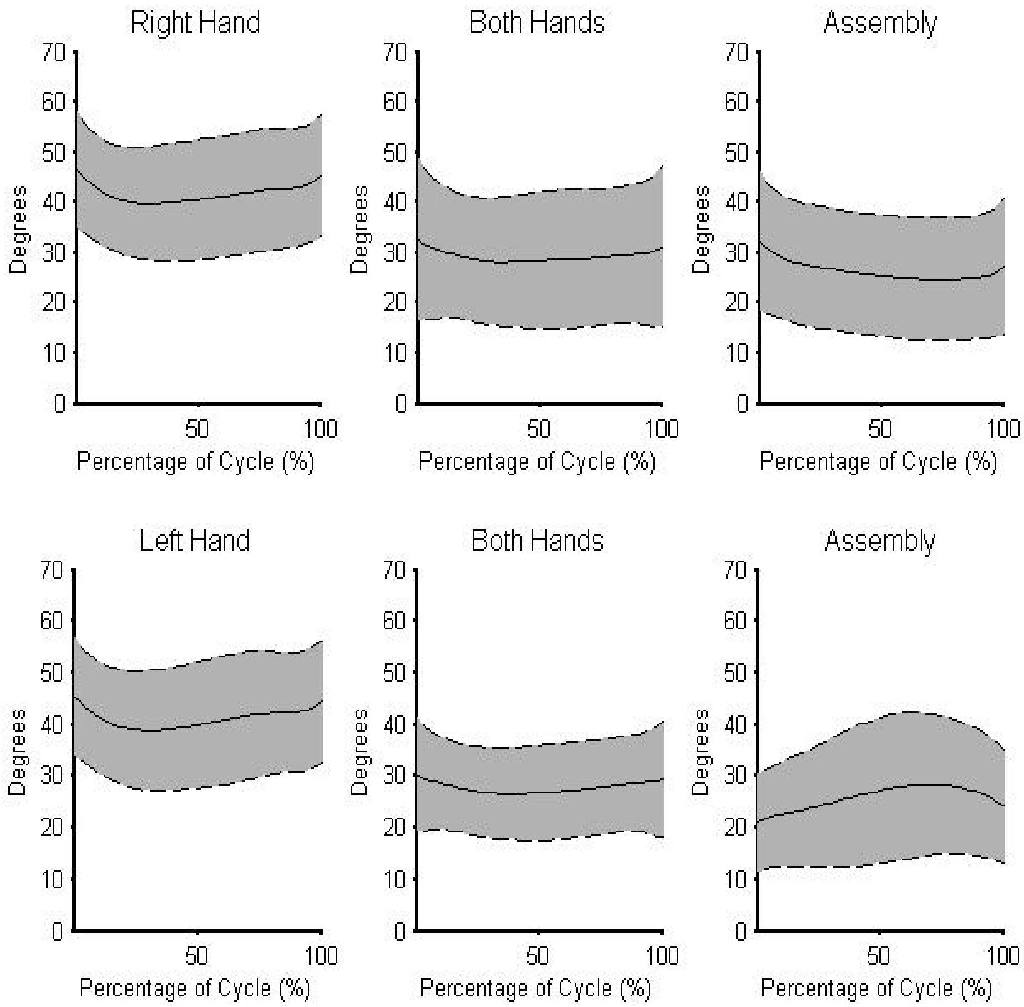


Figure D14: Mean right (top) and left (bottom) thoracohumeral +abduction/-adduction kinematic profiles, with +/- one standard deviation, for the Fingertip Dexterity task.

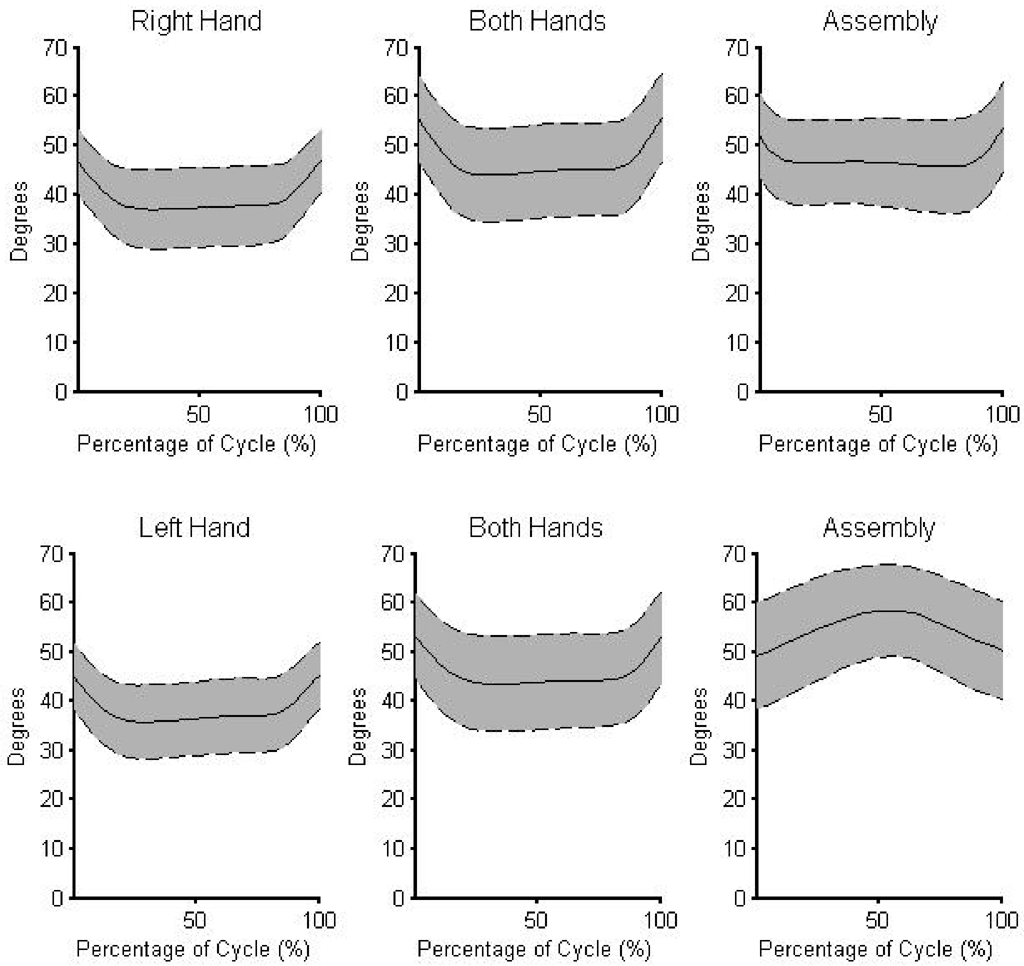


Figure D15: Mean right (top) and left (bottom) thoracohumeral +flexion/-extension kinematic profiles, with +/- one standard deviation, for the Fingertip Dexterity task.

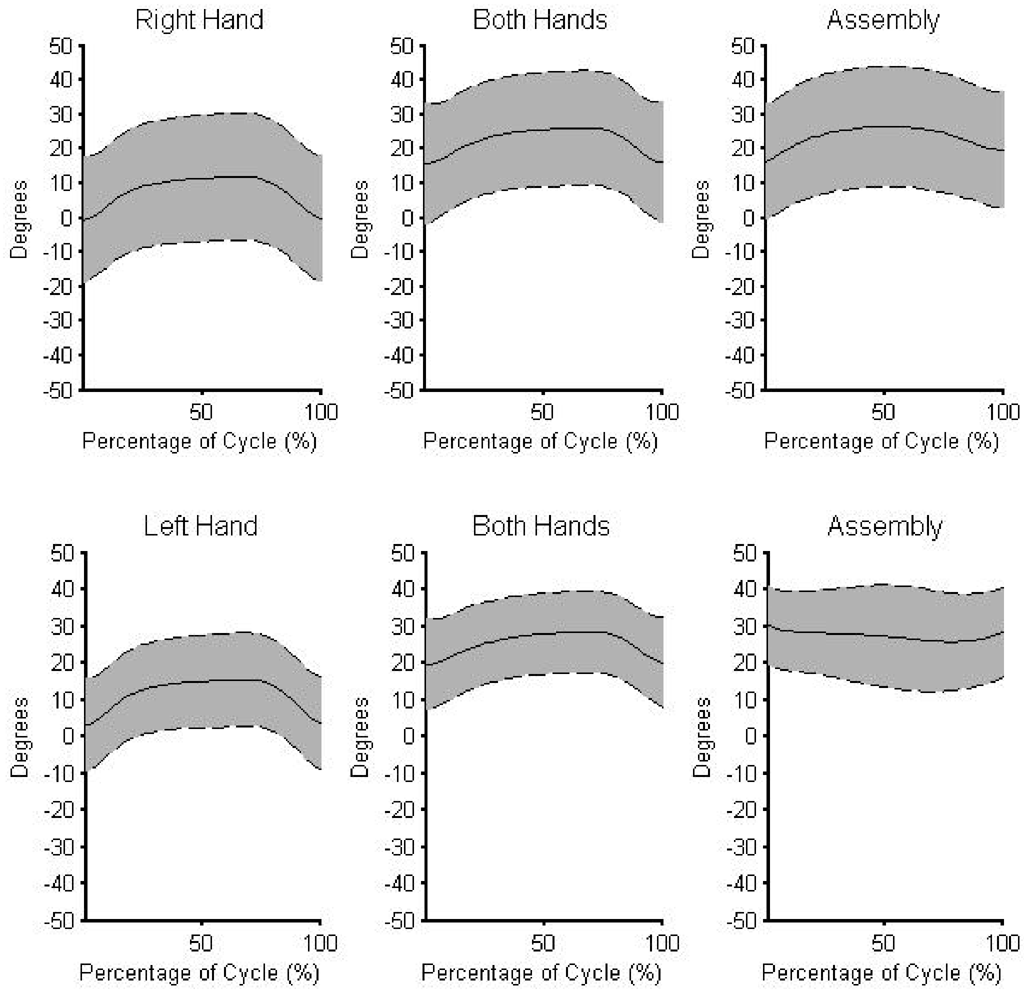


Figure D16: Mean right (top) and left (bottom)thoracohumeral +internal/-external axial rotation kinematic profiles, with +/- one standard deviation, for the Fingertip Dexterity task.

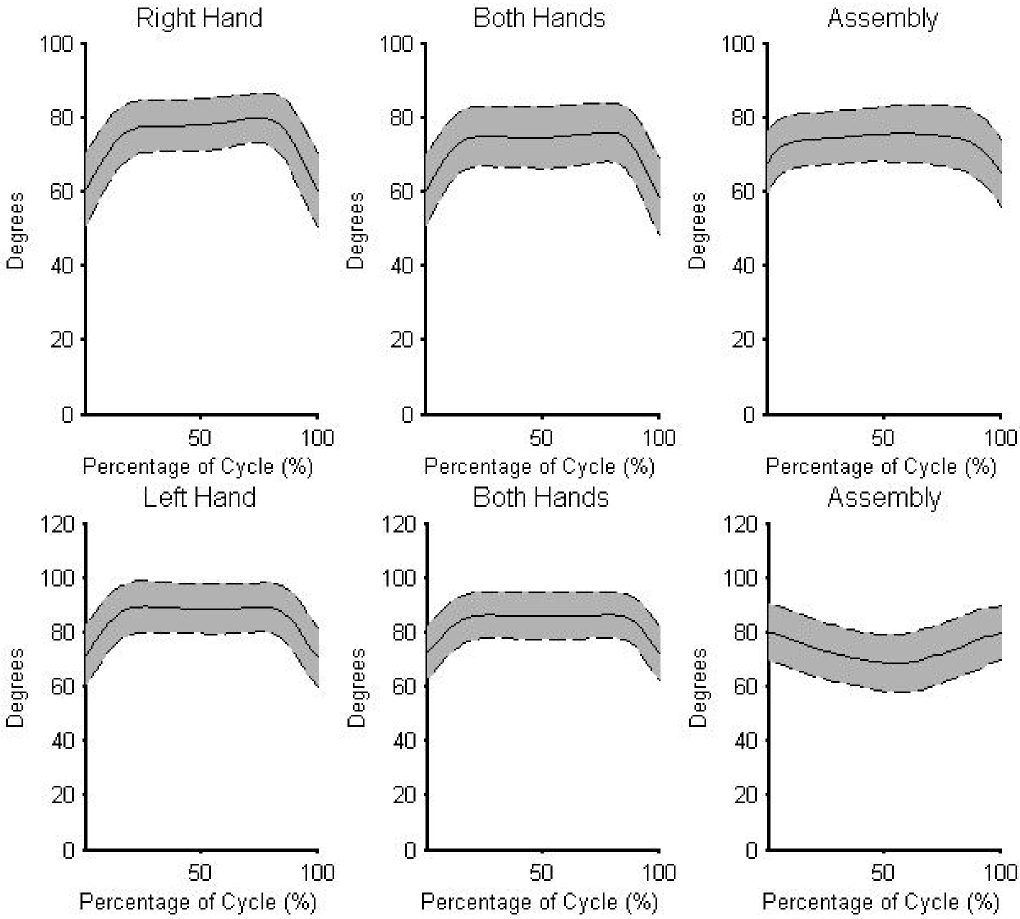


Figure D17: Mean right (top) and left (bottom) elbow +flexion/-hyperextension kinematic profiles, with +/- one standard deviation, for the Fingertip Dexterity task.

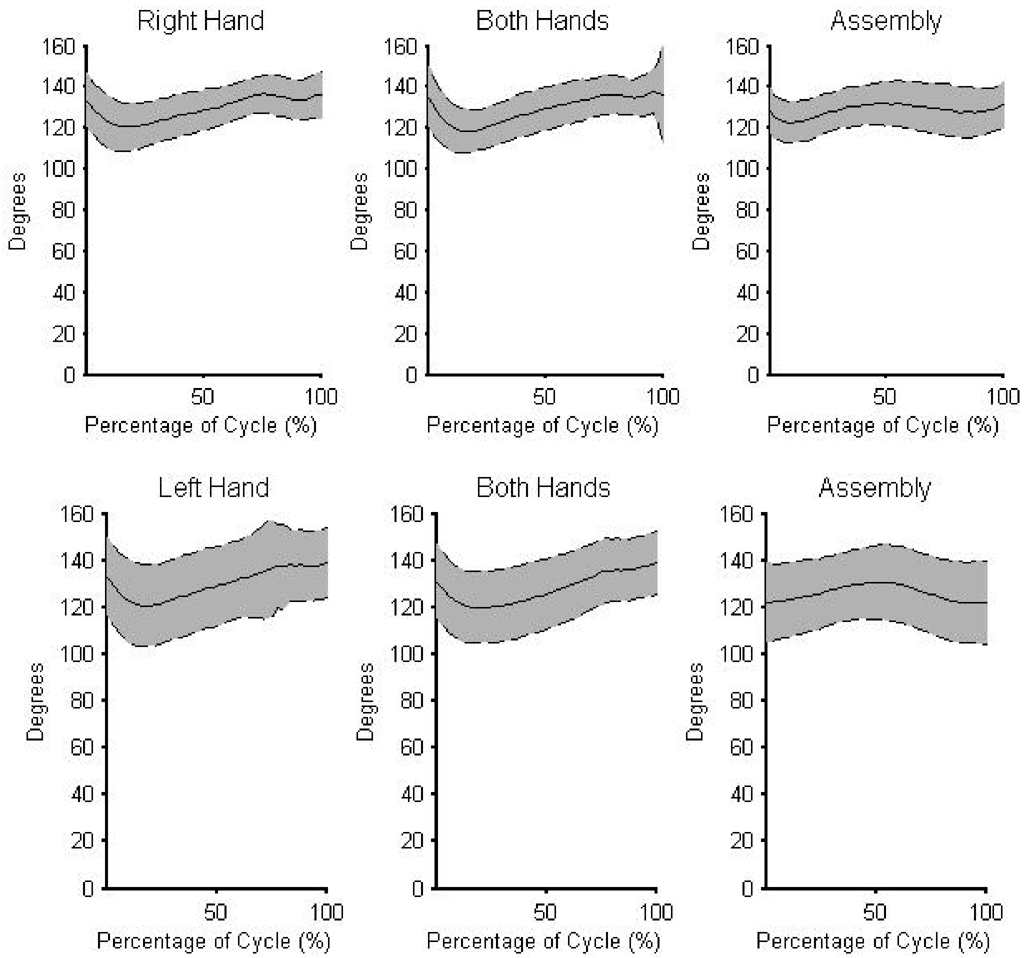


Figure D18: Mean right (top) and left (bottom) elbow +pronation kinematic profiles, with +/- one standard deviation, for the Fingertip Dexterity task.

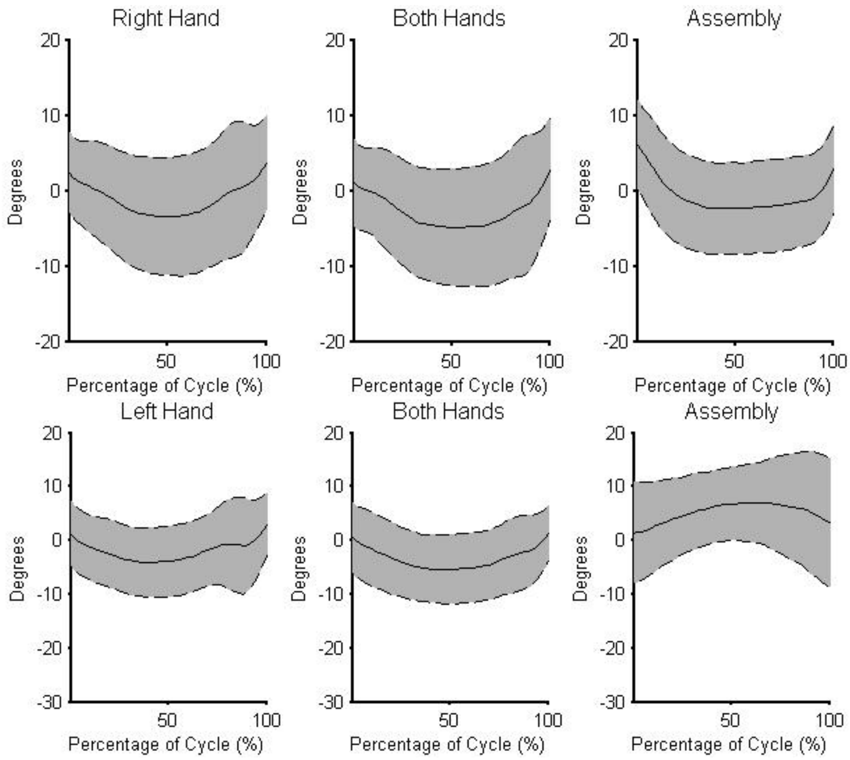


Figure D19: Mean right (top) and left (bottom) wrist +flexion/-extension kinematic profiles, with +/- one standard deviation, for the Fingertip Dexterity task.

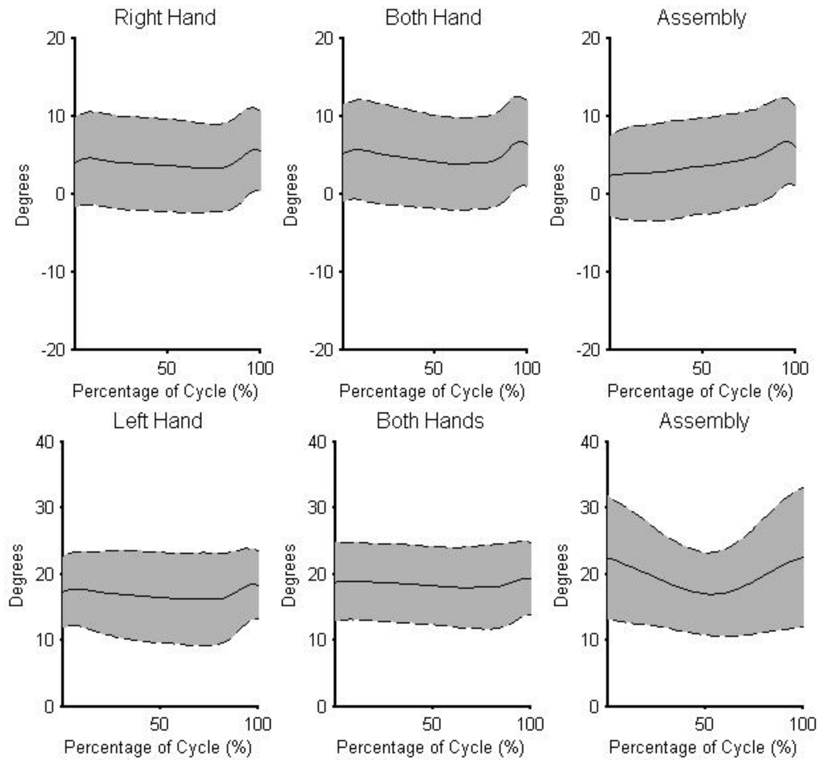


Figure D20: Mean right (top) and left (bottom) wrist +ulnar/-radial deviation kinematic profiles, with +/- one standard deviation, for the Fingertip Dexterity task.

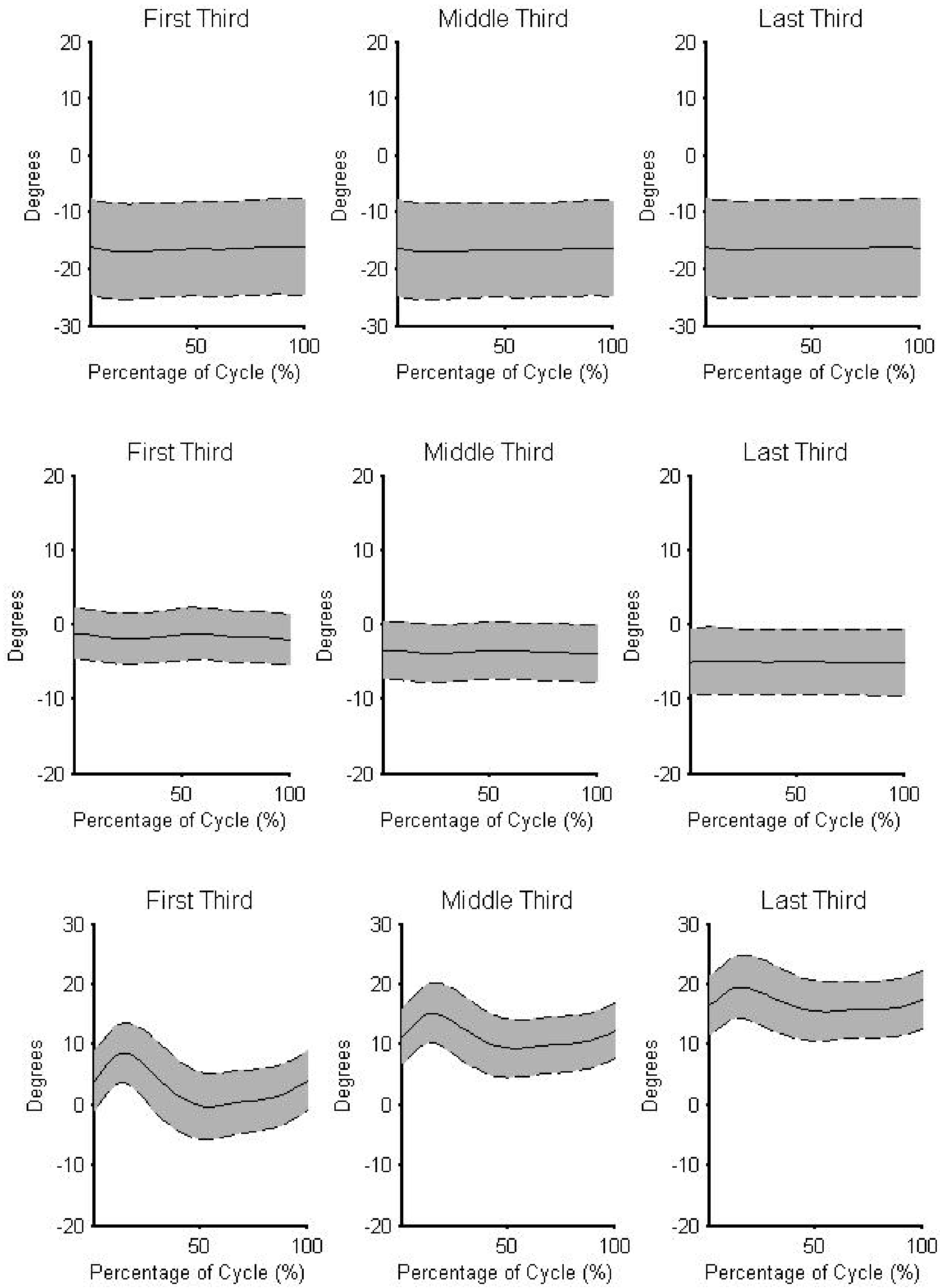


Figure D21: Mean torso +extension/-flexion (top), +right/-left lateral flexion (middle) +left/-right axial rotation (bottom) kinematic profiles, with +/- one standard deviation, for the Hand and Forearm Dexterity Placing task.

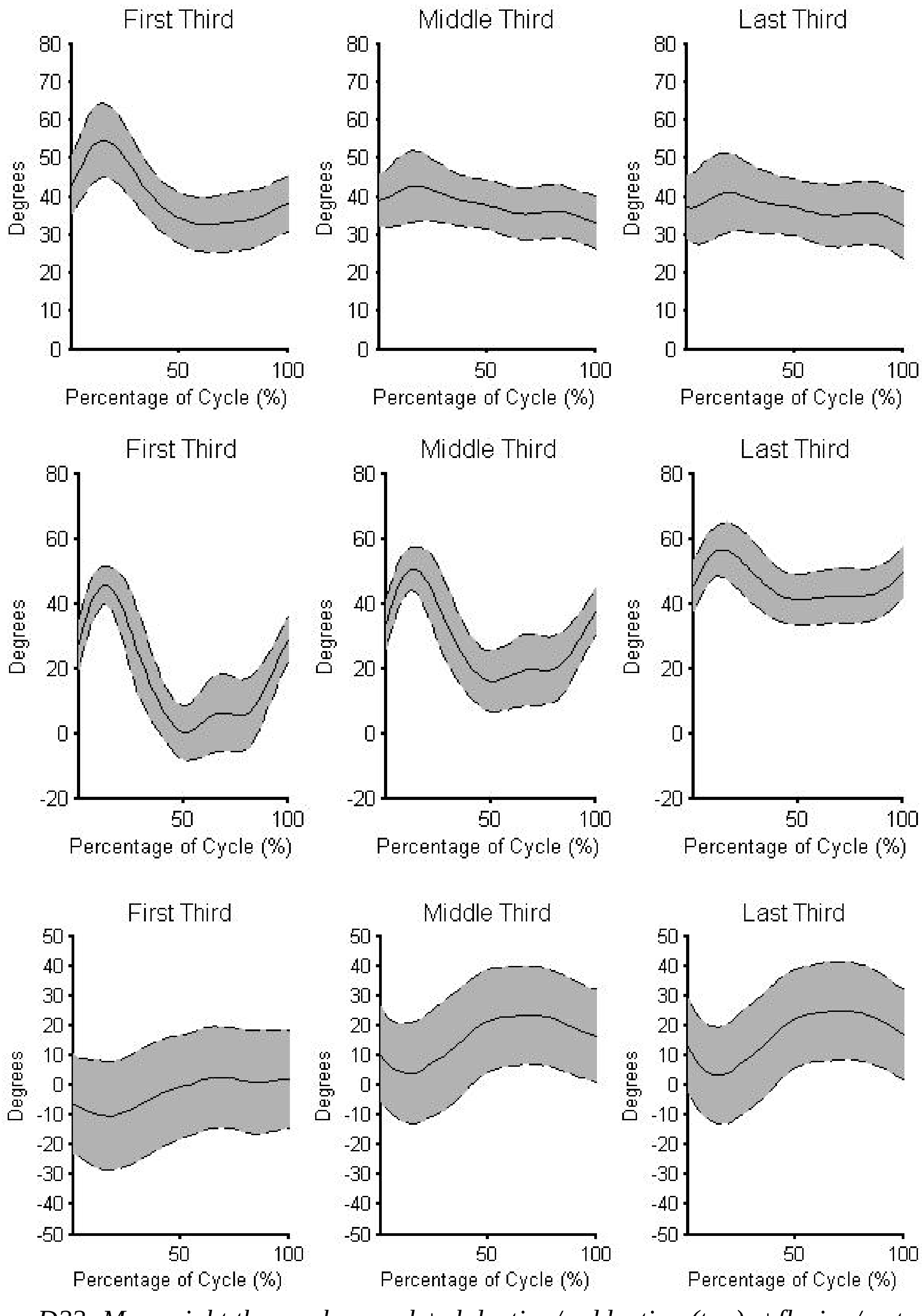
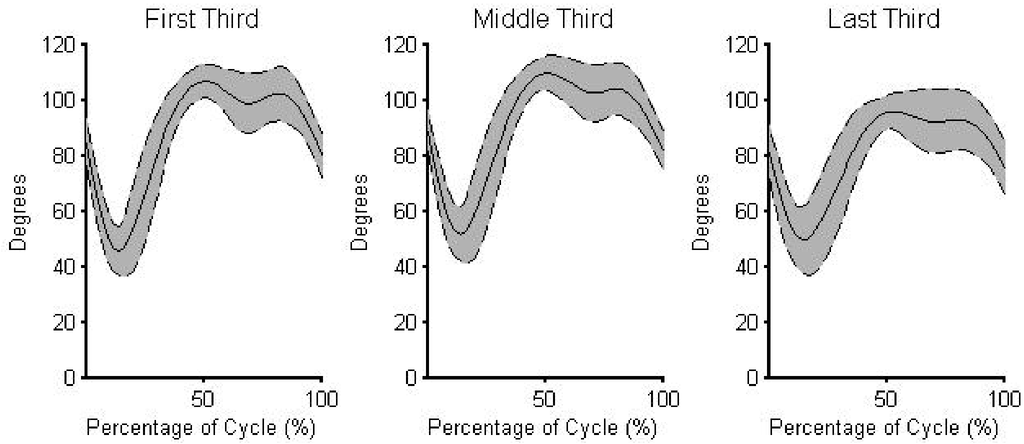


Figure D22: Mean right thoracohumeral +abduction/-adduction (top), +flexion/-extension (middle) +internal/-external axial rotation (bottom) kinematic profiles, with +/- one standard deviation, for the Hand and Forearm Dexterity Placing task.



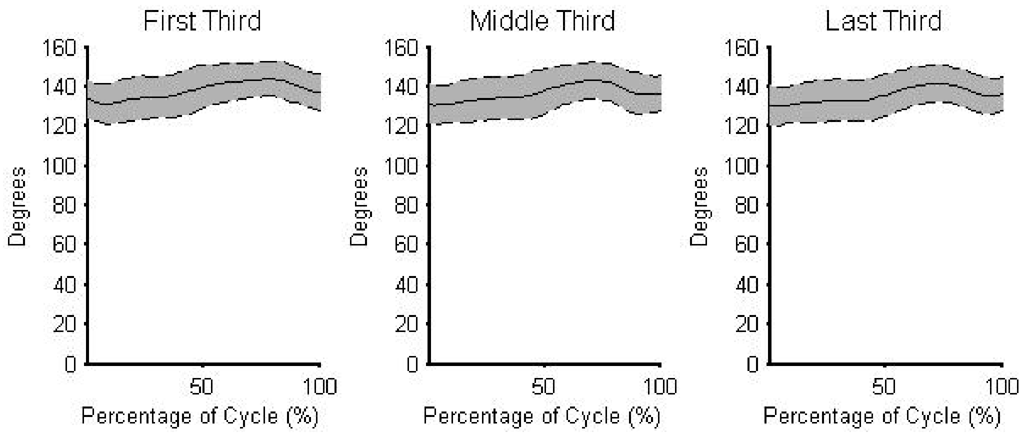


Figure D23: Mean right elbow +flexion/-hyperextension (top), +pronation (bottom) kinematic profiles, with +/- one standard deviation, for the Hand and Forearm Dexterity Placing task.

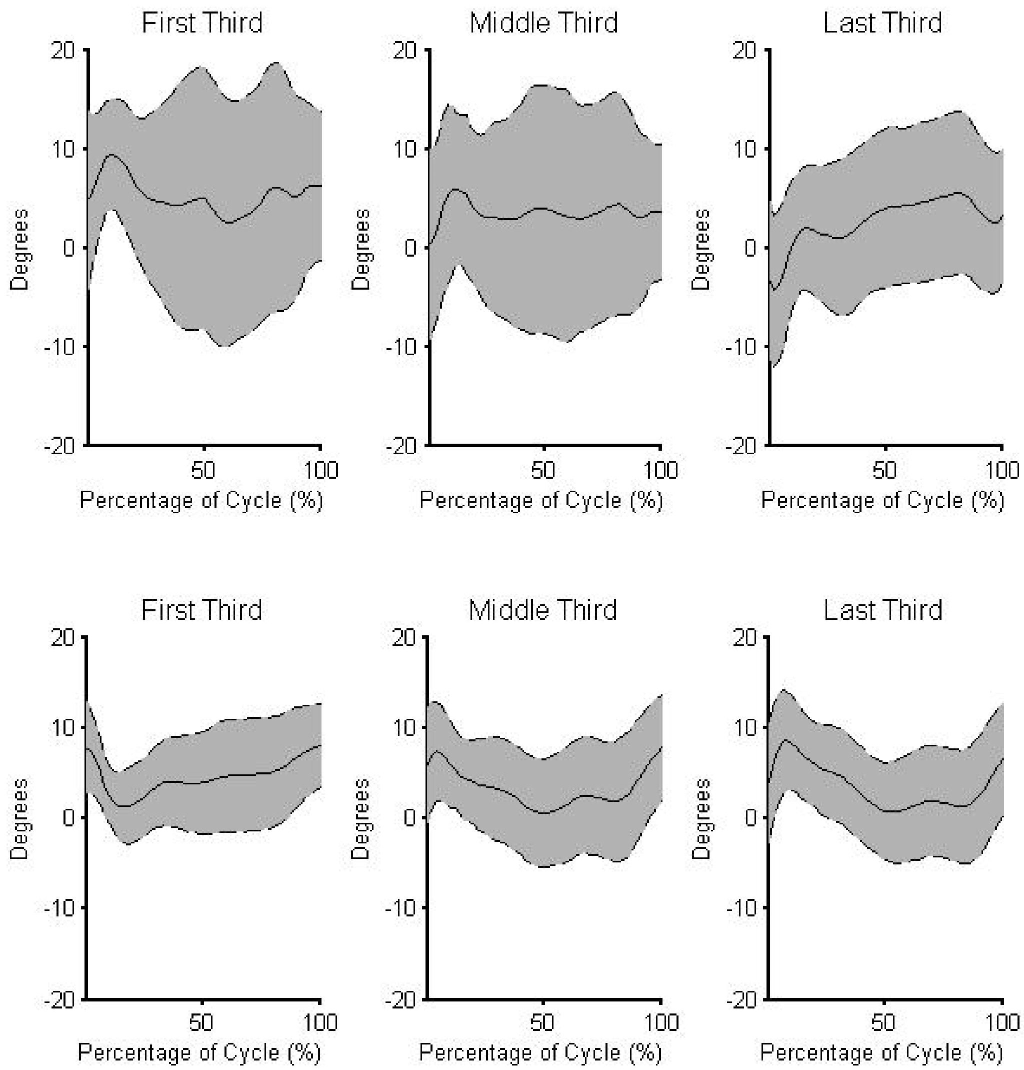


Figure D24: Mean right wrist +flexion/-extension (top), +ulnar/-radial (bottom) kinematic profiles, with +/- one standard deviation, for the Hand and Forearm Dexterity Placing task.

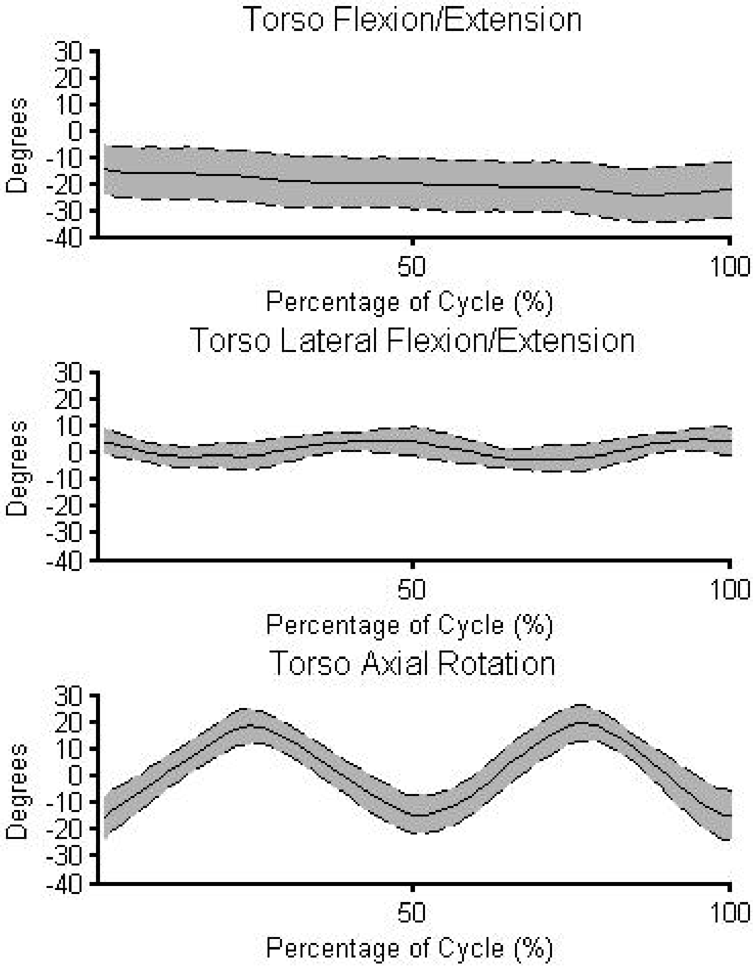


Figure D25: Mean torso +extension/-flexion (top), +right/-left lateral flexion (middle) +left/-right axial rotation (bottom) kinematic profiles, with +/- one standard deviation, for the Hand and Forearm Dexterity Turning task.

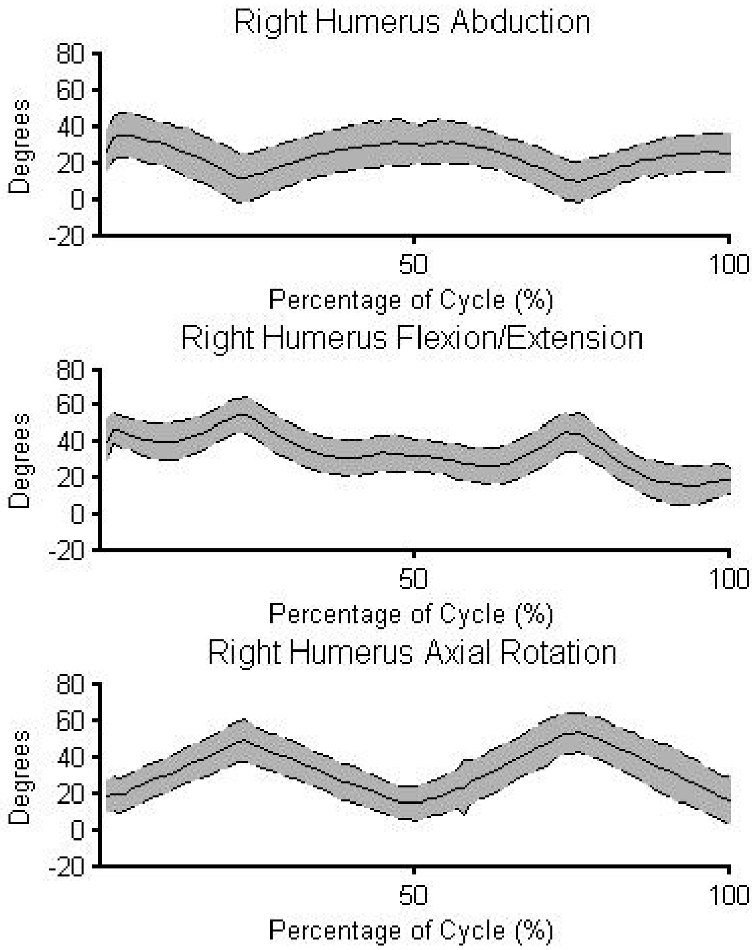


Figure D26: Mean right thoracohumeral +abduction/-adduction (top), +flexion/-extension (middle) +internal/-external axial rotation (bottom) kinematic profiles, with +/- one standard deviation, for the Hand and Forearm Dexterity Turning task.

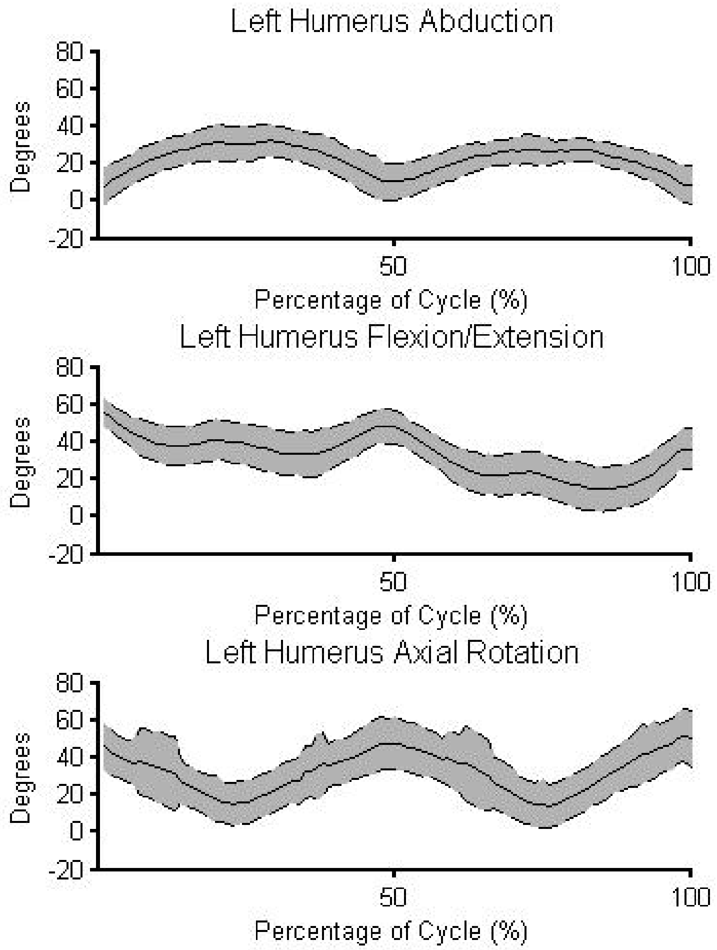


Figure D27: Mean left thoracohumeral +abduction/-adduction (top), +flexion/-extension (middle) +internal/-external axial rotation (bottom) kinematic profiles, with +/- one standard deviation, for the Hand and Forearm Dexterity Turning task.

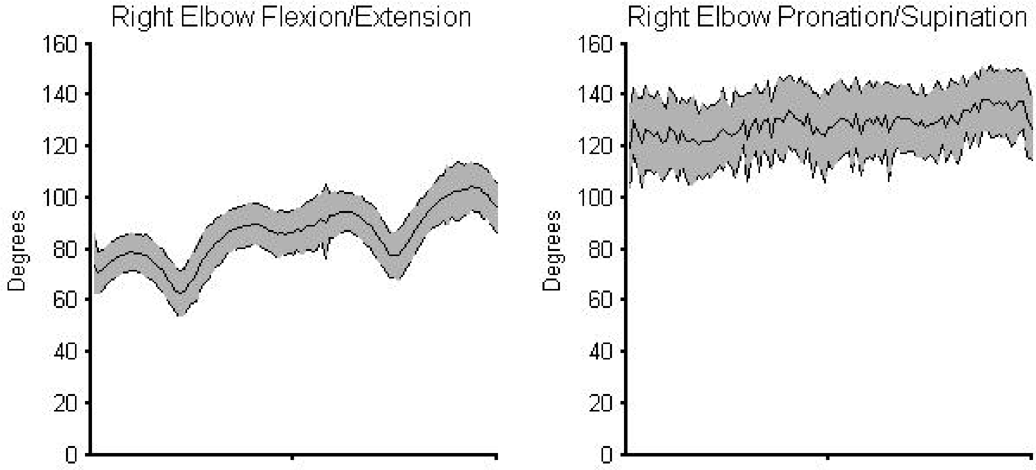


Figure D28: Mean right elbow +flexion/-hyperextension (left) +pronation (right) kinematic profiles, with +/- one standard deviation, for the Hand and Forearm Dexterity Turning task.

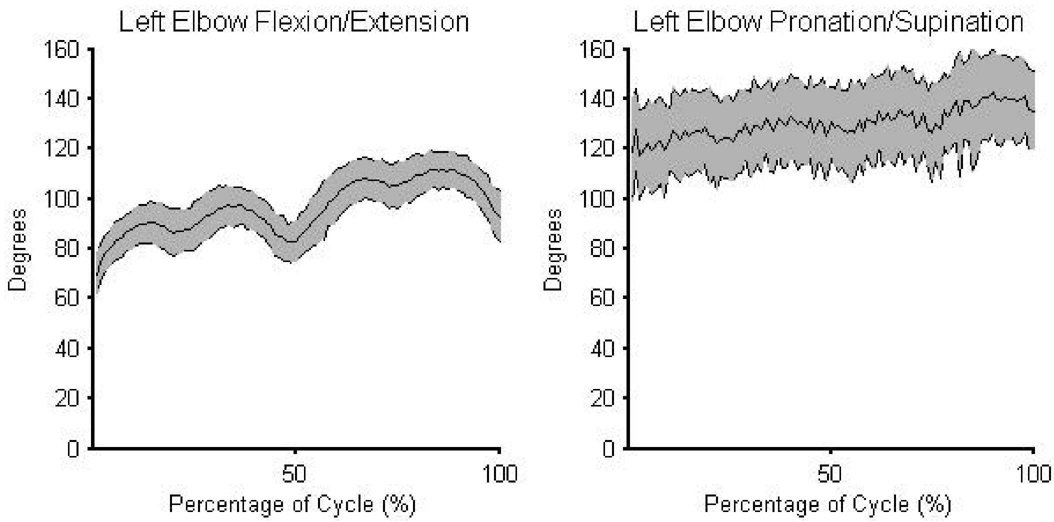


Figure D29: Mean left elbow +flexion/-hyperextension (left) +pronation (right) kinematic profiles, with +/- one standard deviation, for the Hand and Forearm Dexterity Turning task.

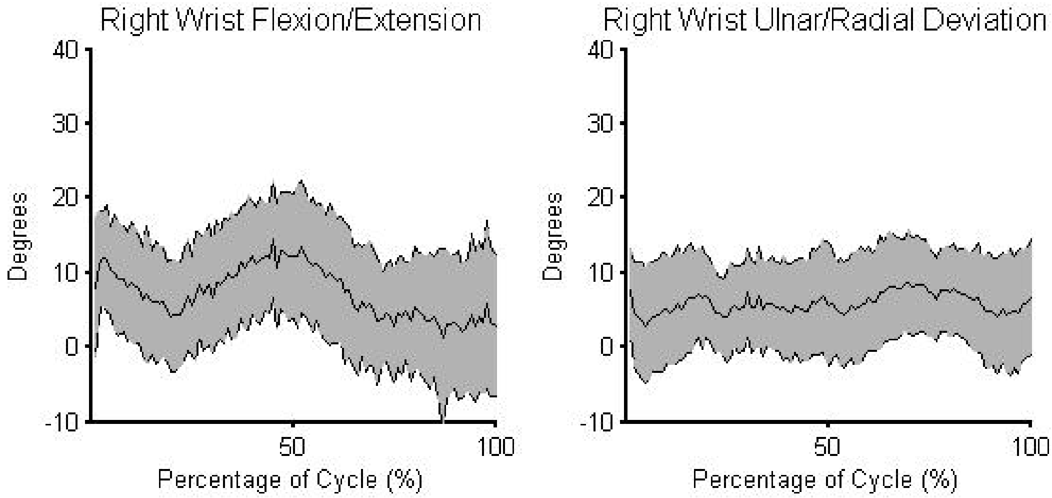


Figure D30: Mean right wrist +flexion/-extension (left) +ulnar/-radial deviation (right) kinematic profiles, with +/- one standard deviation, for the Hand and Forearm Dexterity Turning task.

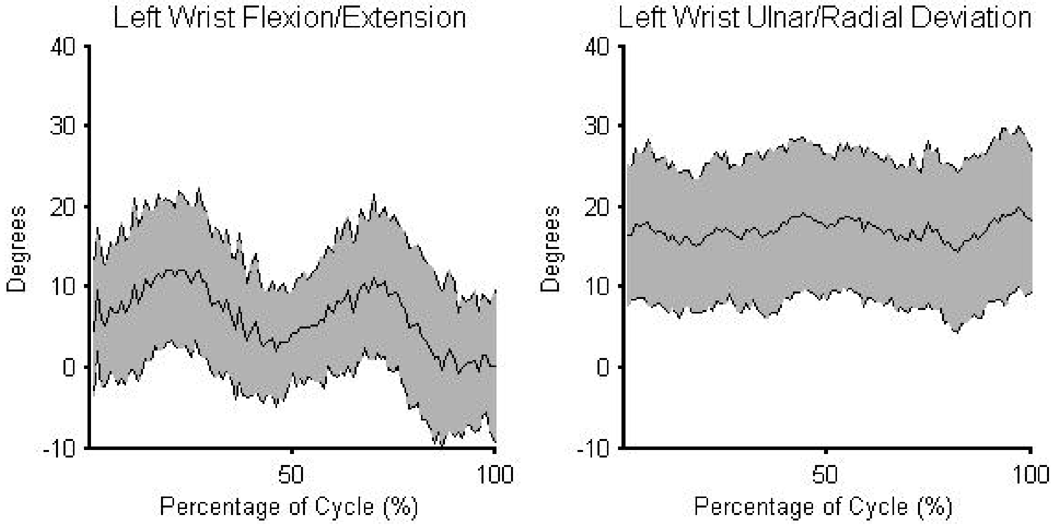


Figure D31: Mean left wrist +flexion/-extension (left) +ulnar/-radial deviation (right) kinematic profiles, with +/- one standard deviation, for the Hand and Forearm Dexterity Turning task.

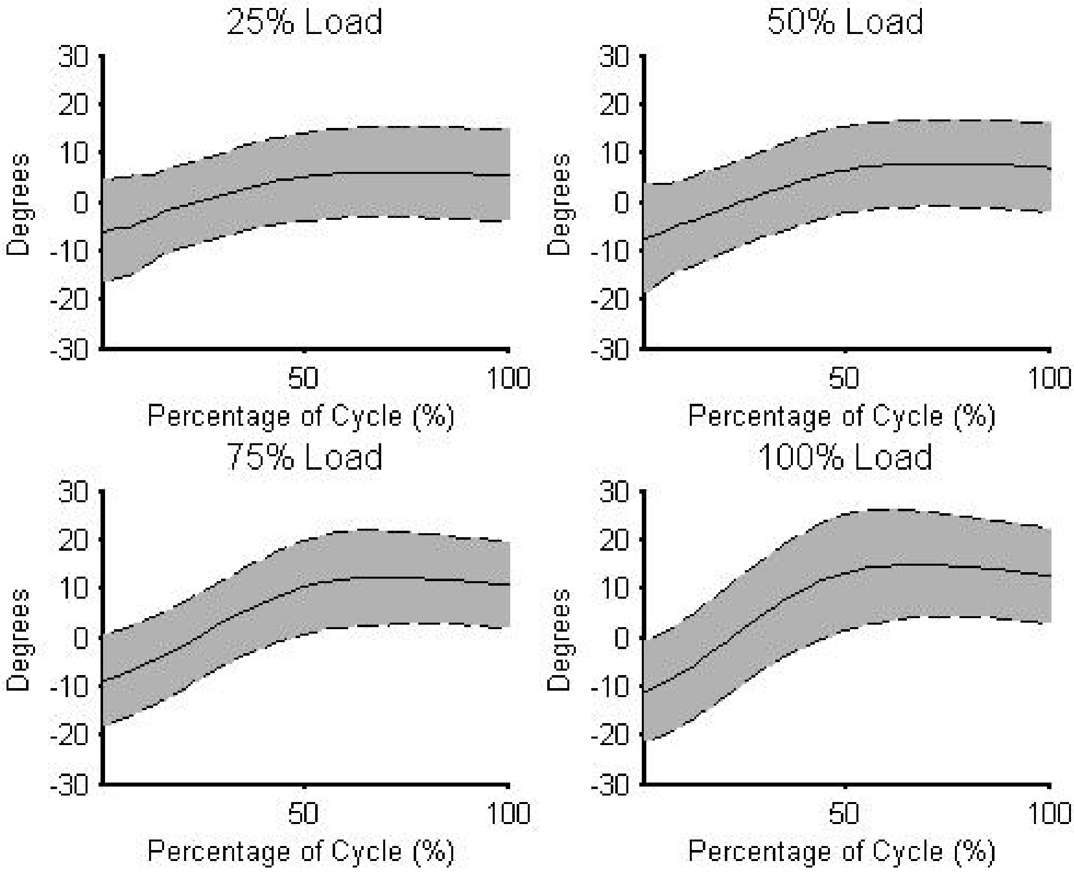


Figure D32: Mean torso +extension/-flexion kinematic profiles, with +/- one standard deviation, for the Waist to Overhead Lift task.

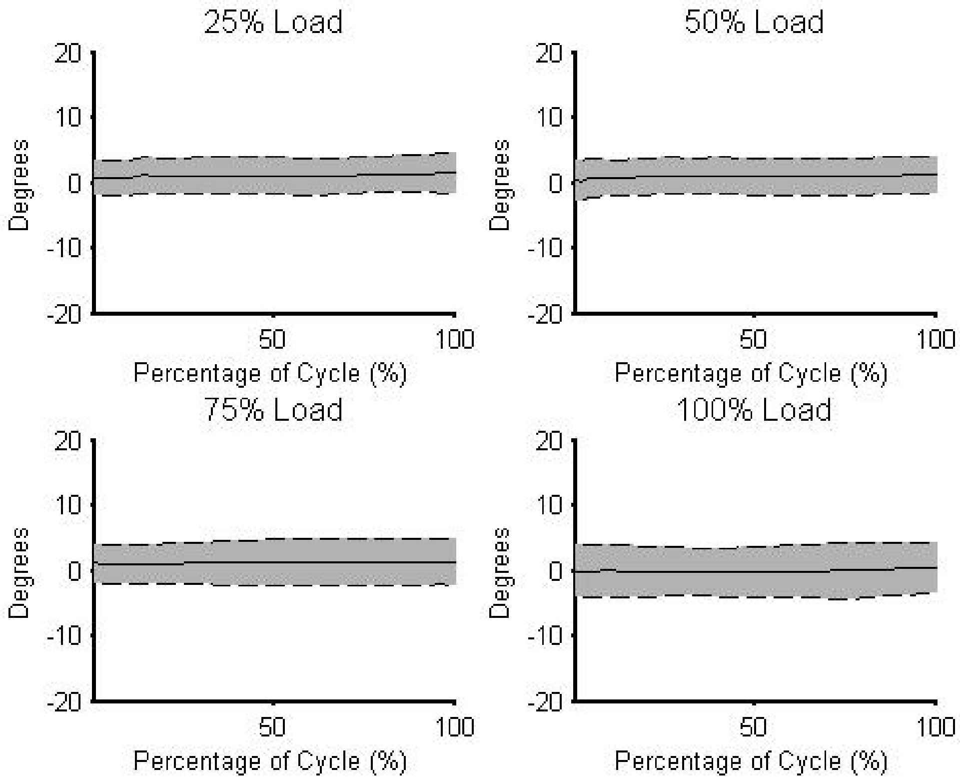


Figure D33: Mean torso +right/-left lateral flexion kinematic profiles, with +/- one standard deviation, for the Waist to Overhead Lift task.

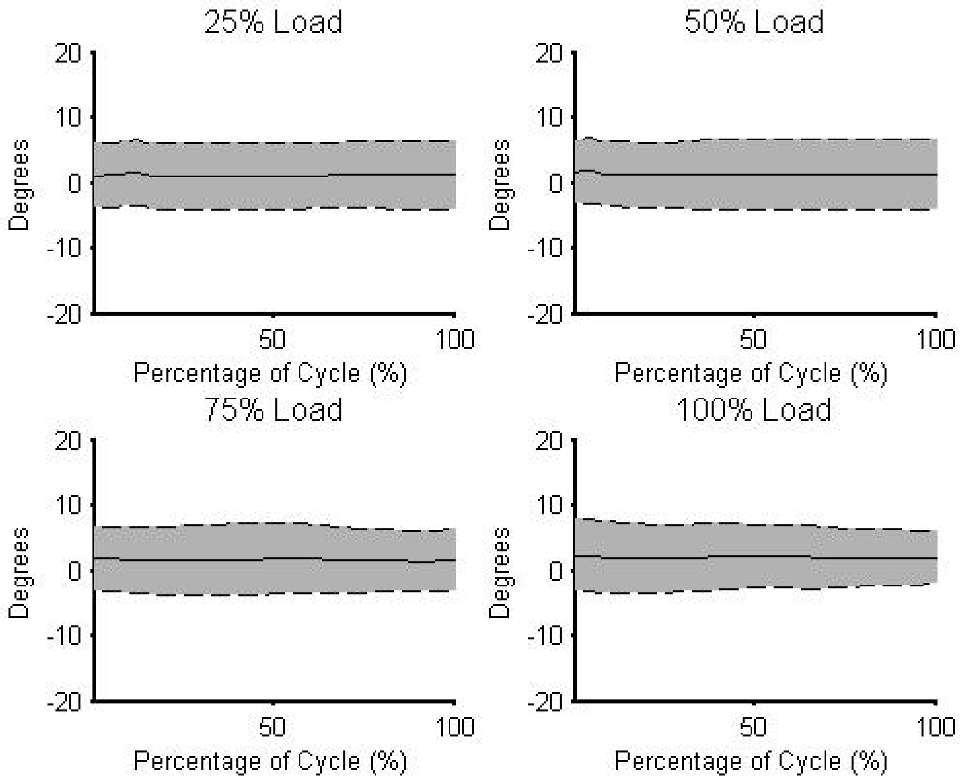


Figure D34: Mean torso +left/-right axial rotation kinematic profiles, with +/- one standard deviation, for the Waist to Overhead Lift task.

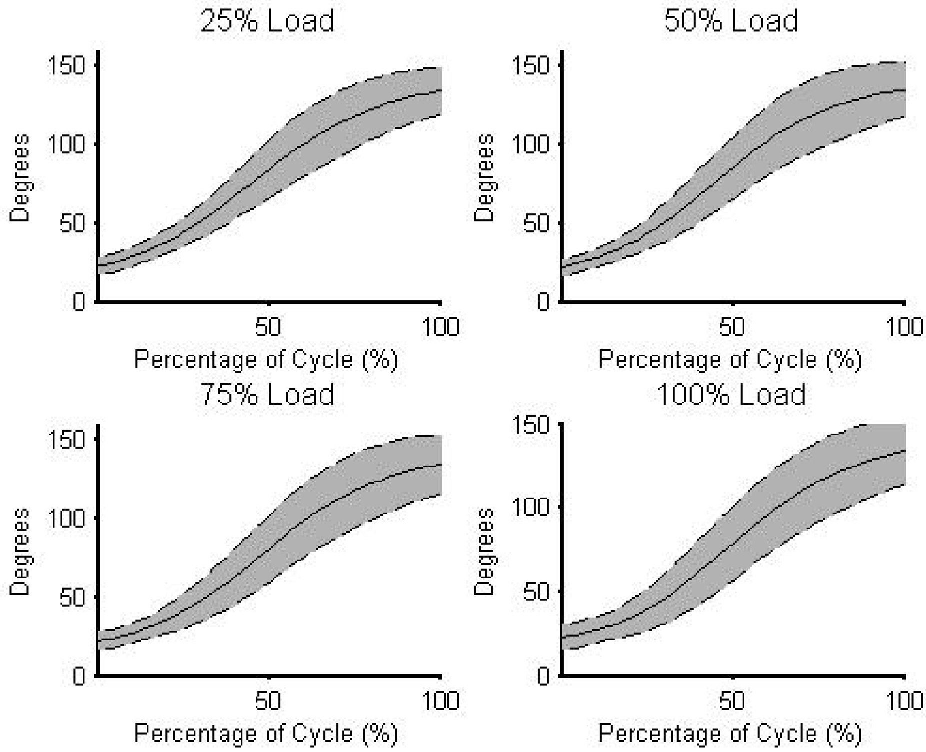


Figure D35: Mean right thoracohumeral +abduction/-adduction kinematic profiles, with +/- one standard deviation, for the Waist to Overhead Lift task.

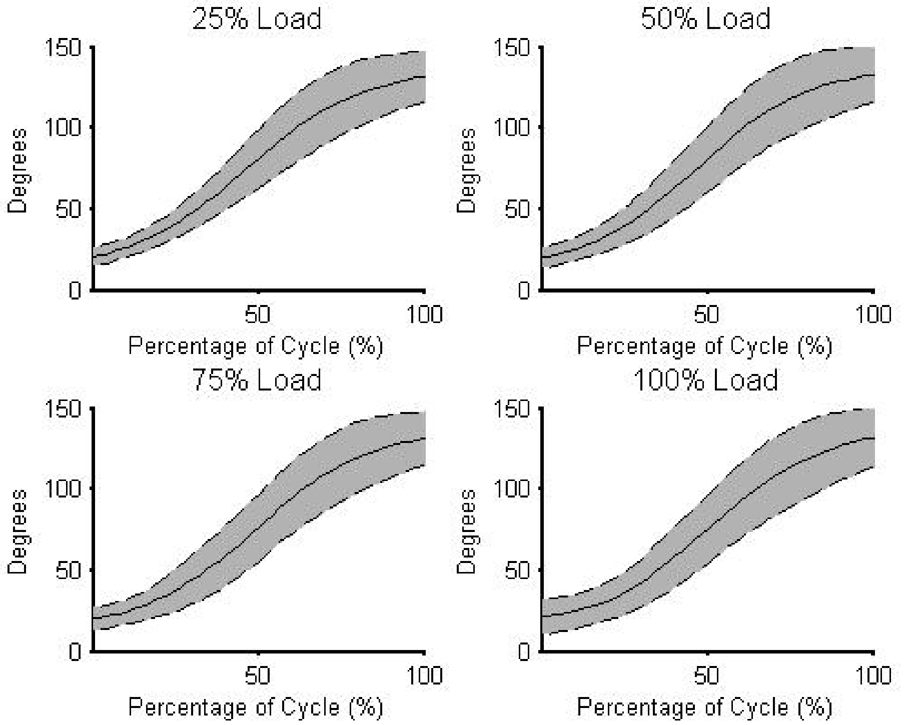


Figure D36: Mean left thoracohumeral +abduction/-adduction kinematic profiles, with +/- one standard deviation, for the Waist to Overhead Lift task.

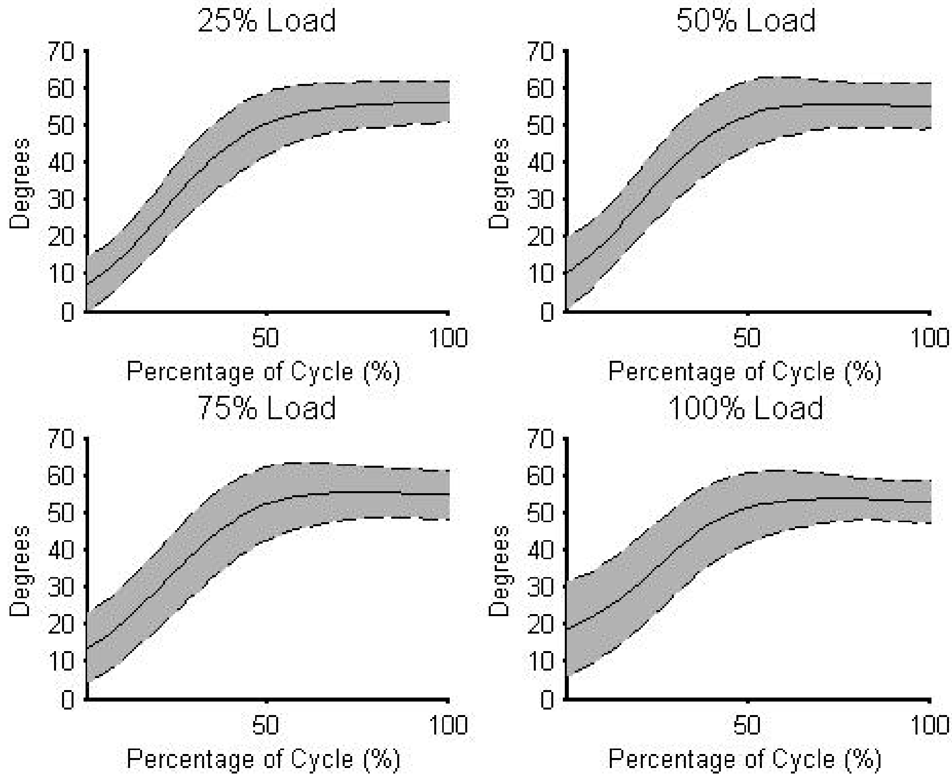


Figure D37: Mean right thoracohumeral +flexion/-extension kinematic profiles, with +/- one standard deviation, for the Waist to Overhead Lift Task.

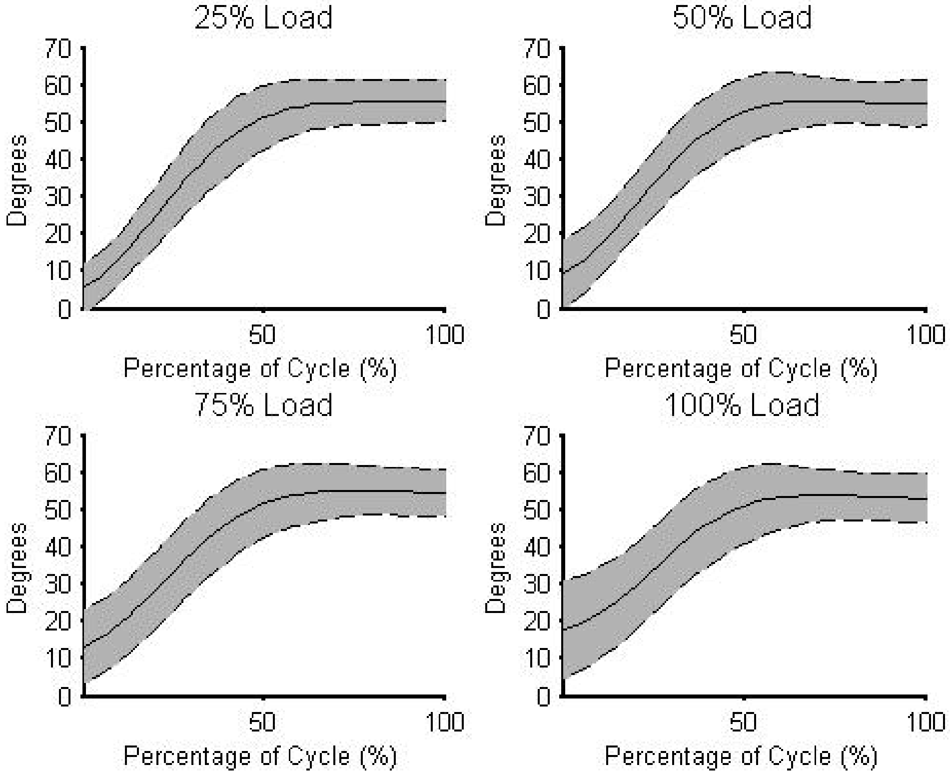


Figure D38: Mean left thoracohumeral +flexion/-extension kinematic profiles, with +/- one standard deviation, for the Waist to Overhead Lift task.

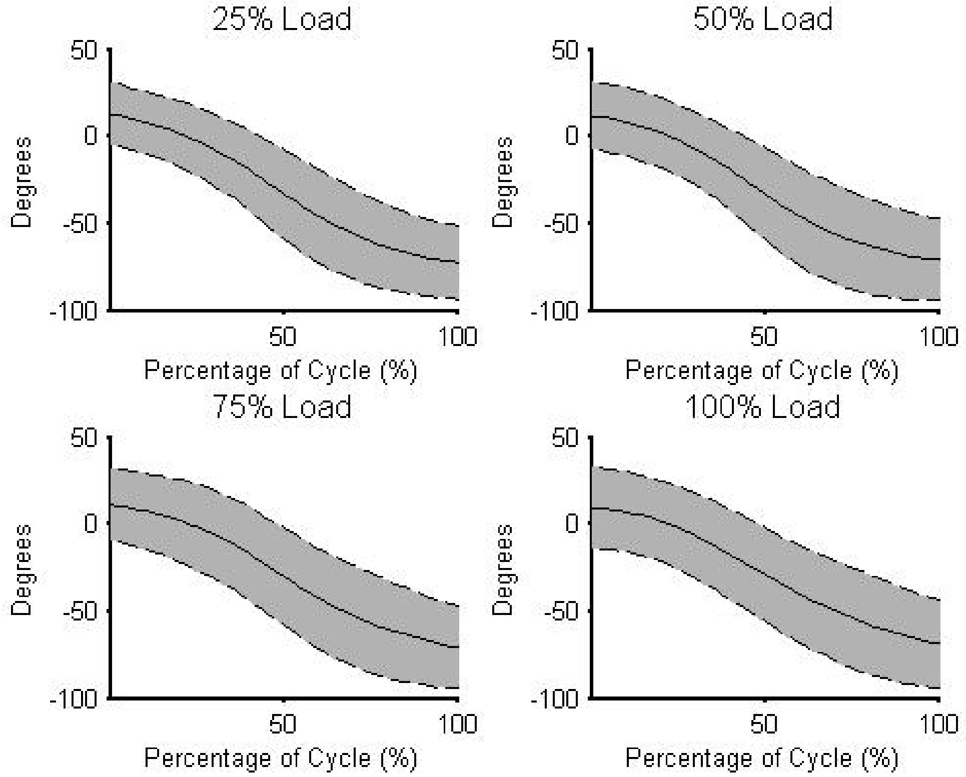


Figure D39: Mean right thoracohumeral +internal/-external axial rotation kinematic profiles, with +/- one standard deviation, for the Waist to Overhead Lift task.

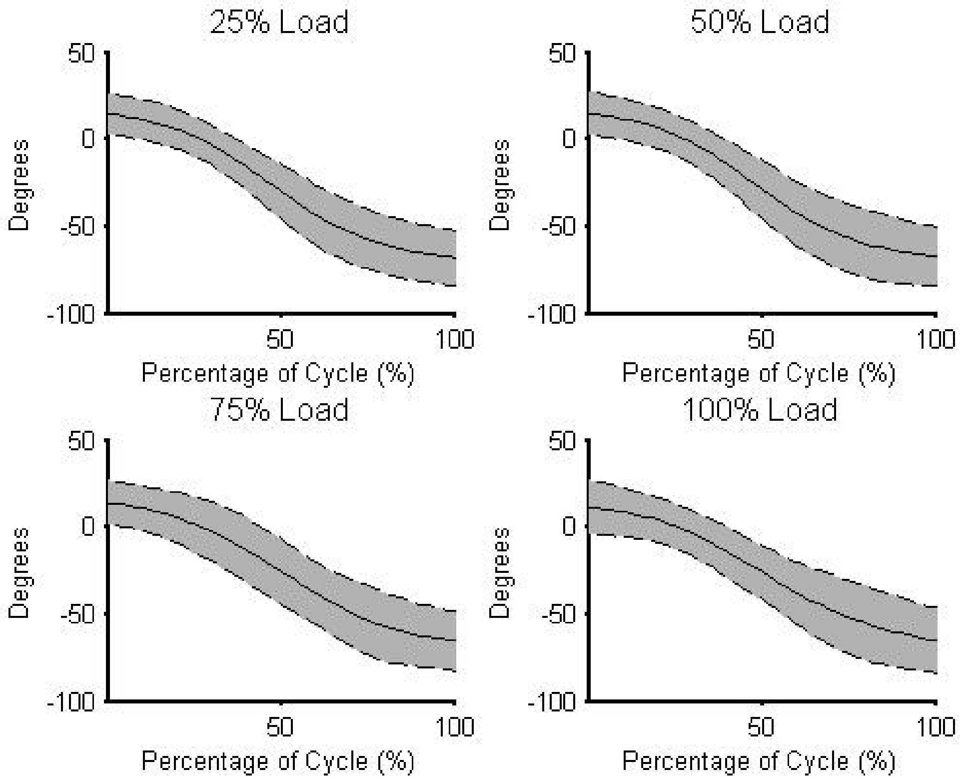


Figure D40: Mean left thoracohumeral +internal/-external axial rotation kinematic profiles, with +/- one standard deviation, for the Waist to Overhead Lift task.

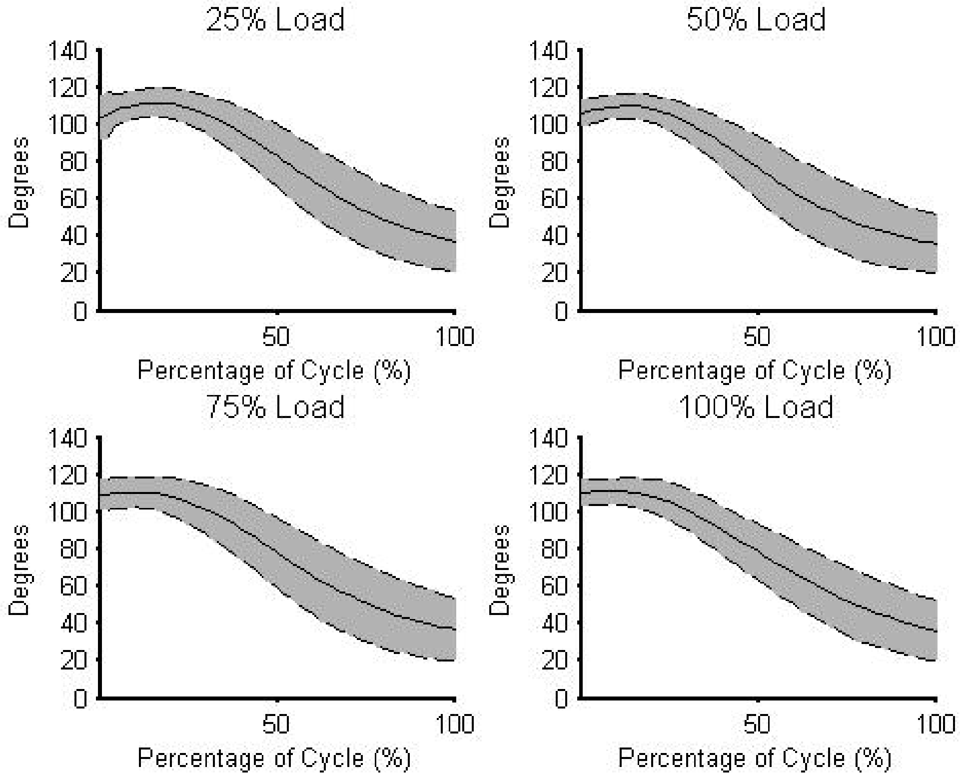


Figure D41: Mean right elbow +flexion/-hyperextension kinematic profiles, with +/- one standard deviation, for the Waist to Overhead Lift task.

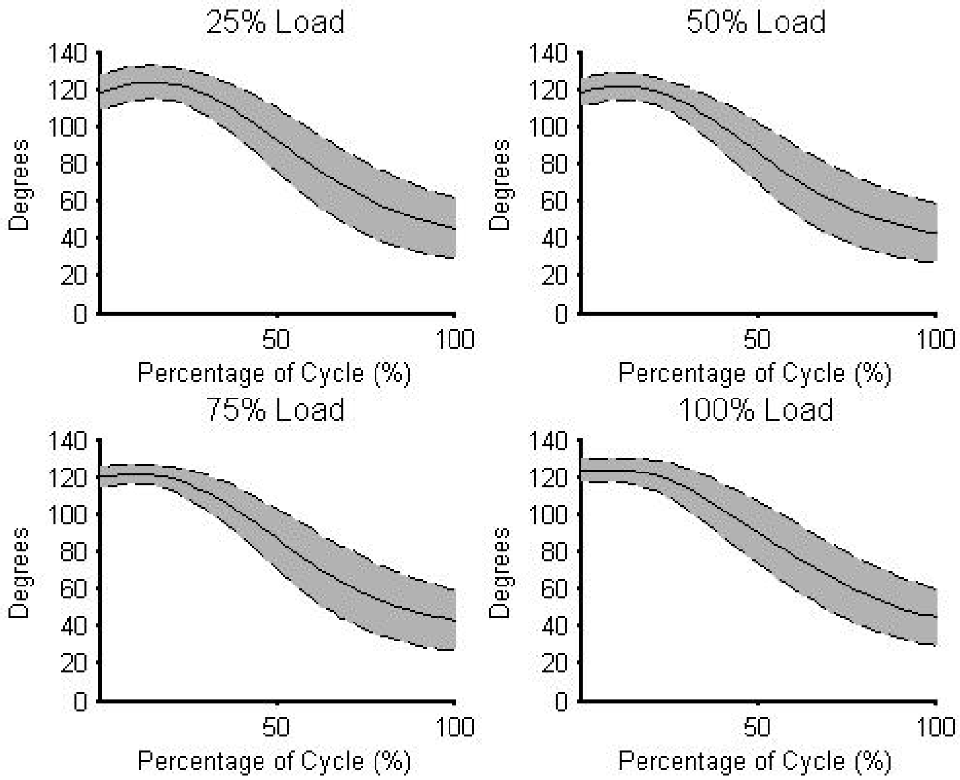


Figure D42: Mean left elbow +flexion/-hyperextension kinematic profiles, with +/- one standard deviation, for the Waist to Overhead Lift task.

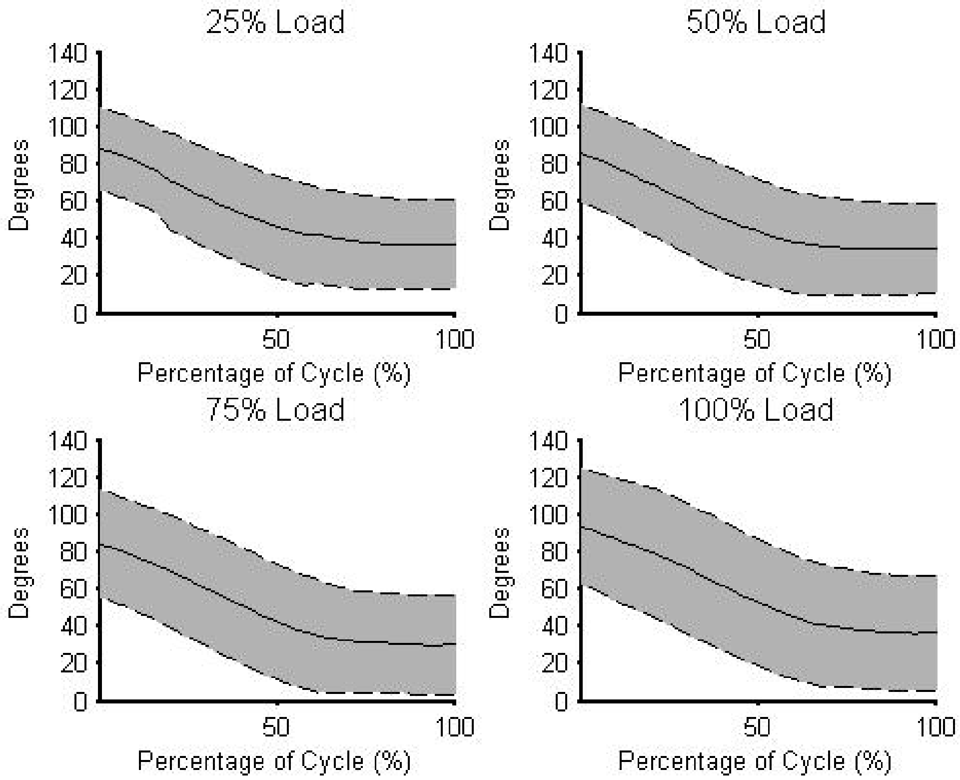


Figure D43: Mean right elbow +pronation kinematic profiles, with +/- one standard deviation, for the Waist to Overhead Lift task.

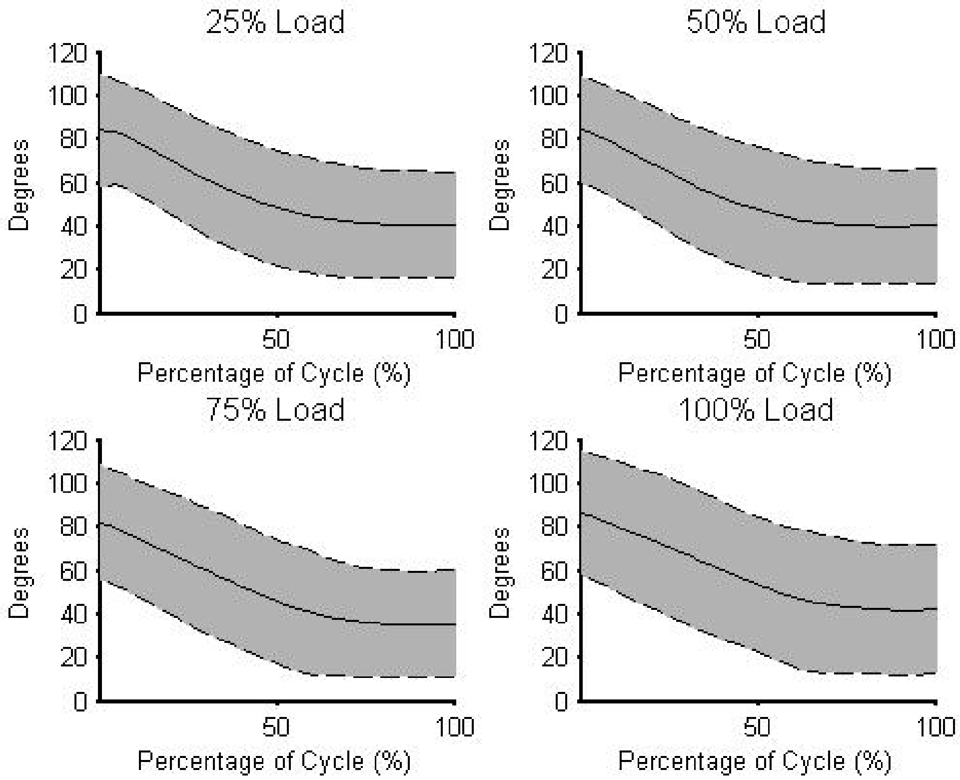


Figure D44: Mean left elbow +pronation kinematic profiles, with +/- one standard deviation, for the Waist to Overhead Lift task.

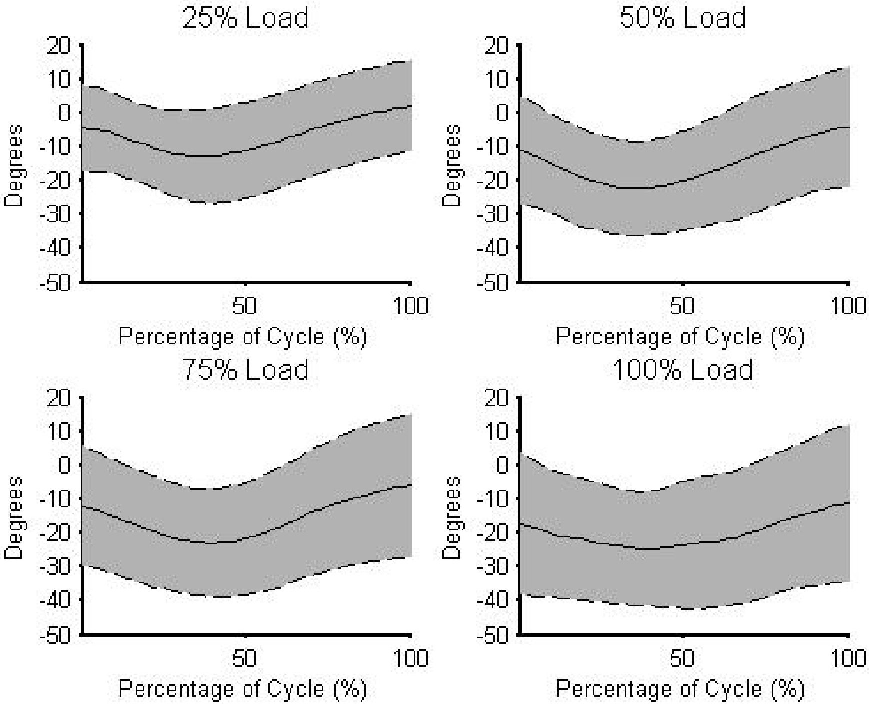


Figure D45: Mean right wrist +flexion/-extension kinematic profiles, with +/- one standard deviation, for the Waist to Overhead Lift task.

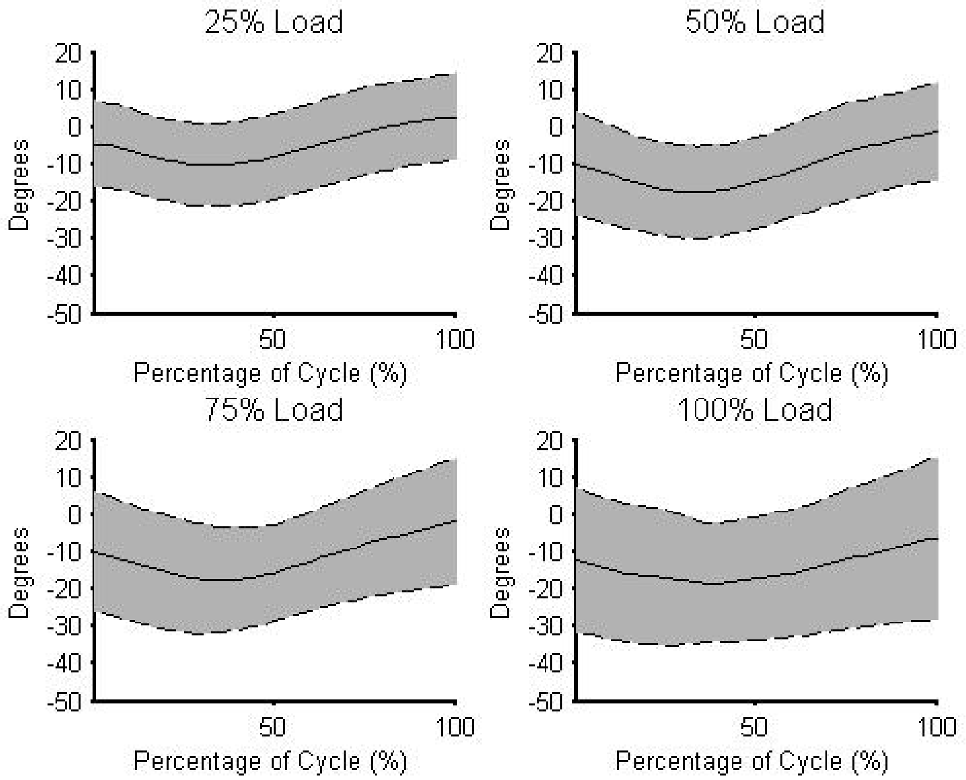


Figure D46: Mean left wrist +flexion/-extension kinematic profiles, with +/- one standard deviation, for the Waist to Overhead Lift task.

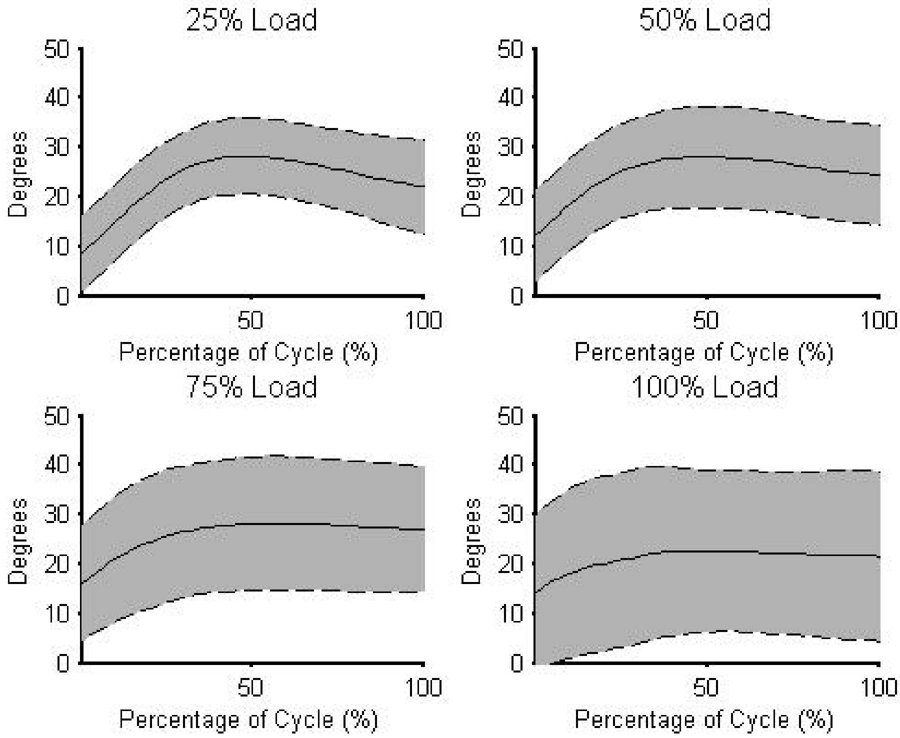


Figure D47: Mean right wrist +ulnar/-radial deviation kinematic profiles, with +/- one standard deviation, for the Waist to Overhead Lift task.

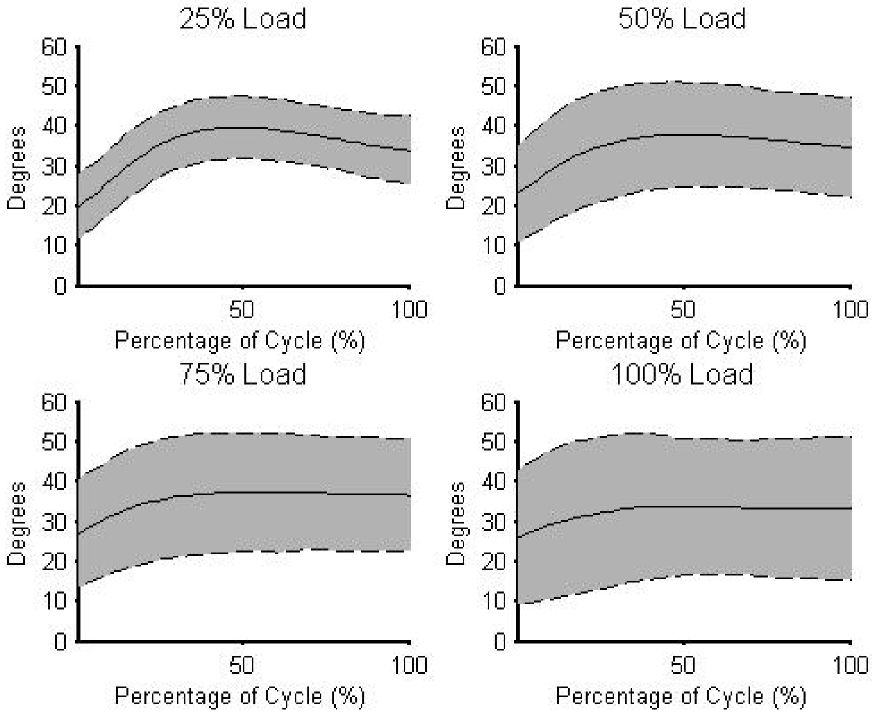


Figure D48: Mean left wrist +ulnar/-radial deviation kinematic profiles, with +/- one standard deviation, for the Waist to Overhead Lift task.

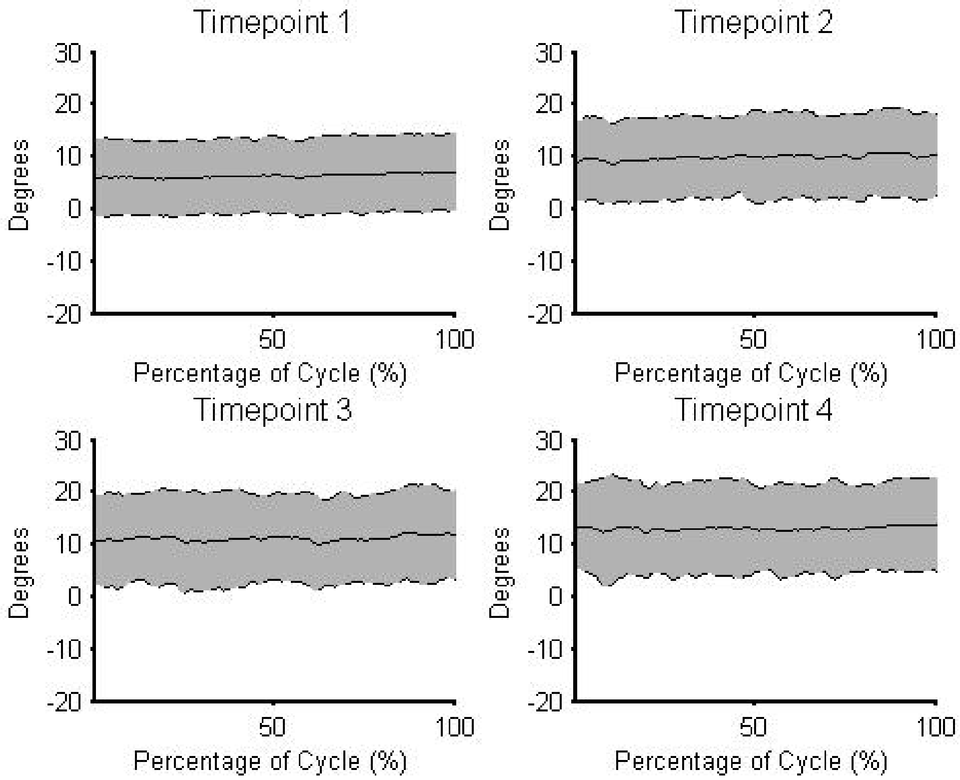


Figure D49: Mean torso +extension/-flexion kinematic profiles, with +/- one standard deviation, for the Overhead Work task.

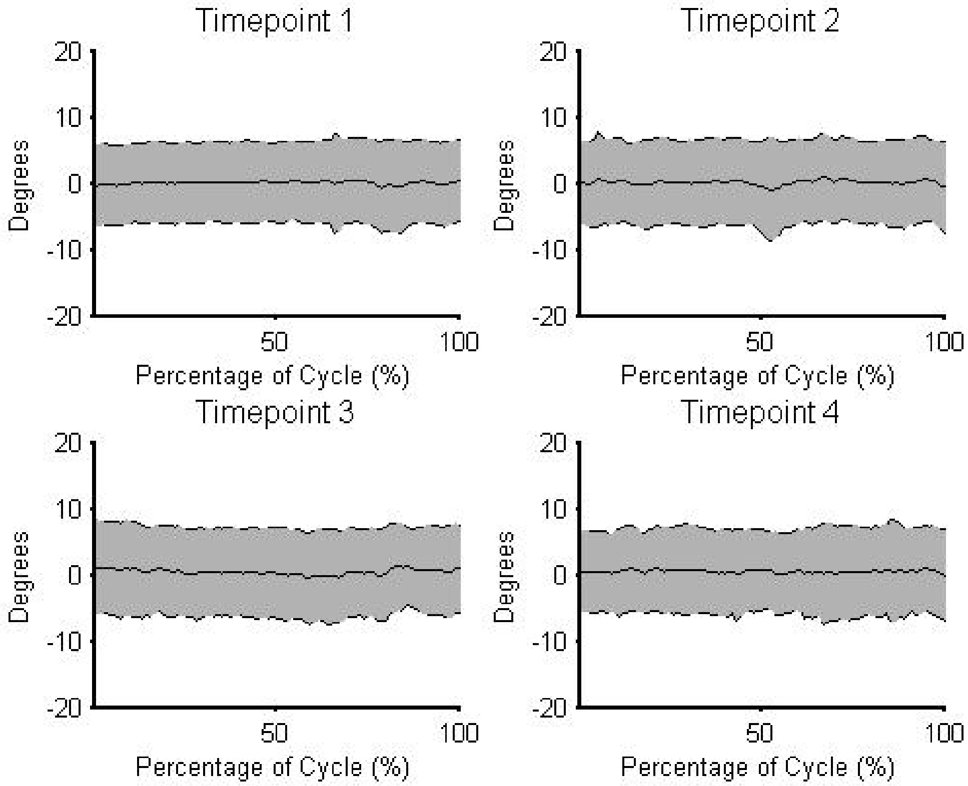


Figure D50: Mean torso +right/-left lateral flexion kinematic profiles, with +/- one standard deviation, for the Overhead Work task.

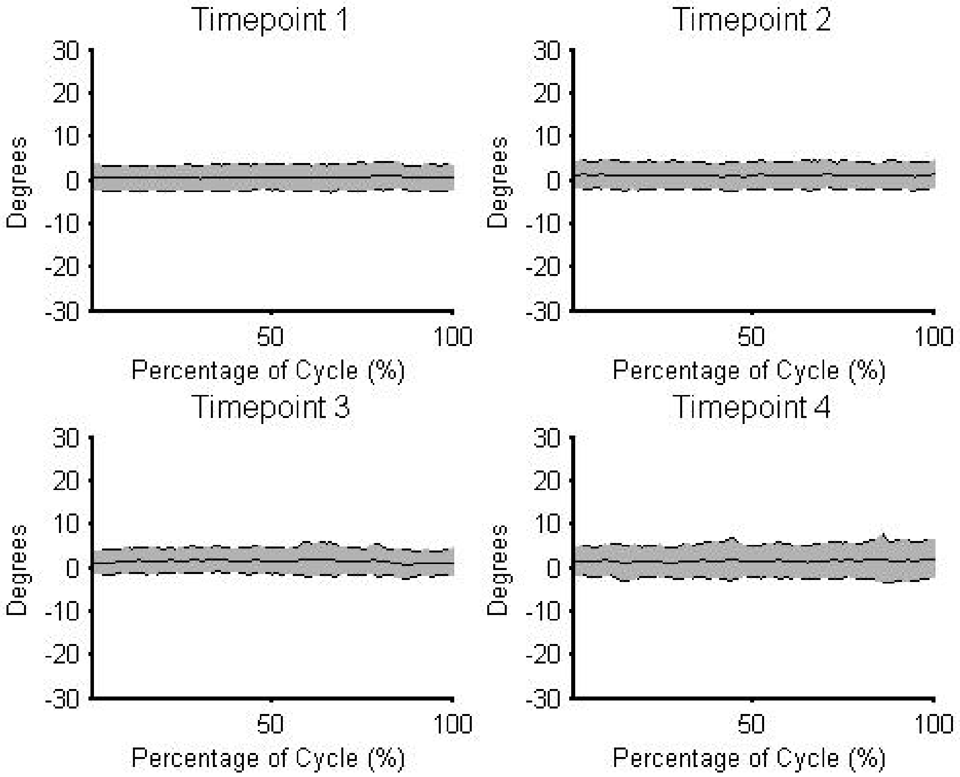


Figure D51: Mean torso +left/-right axial rotation kinematic profiles, with +/- one standard deviation, for the Overhead Work task.

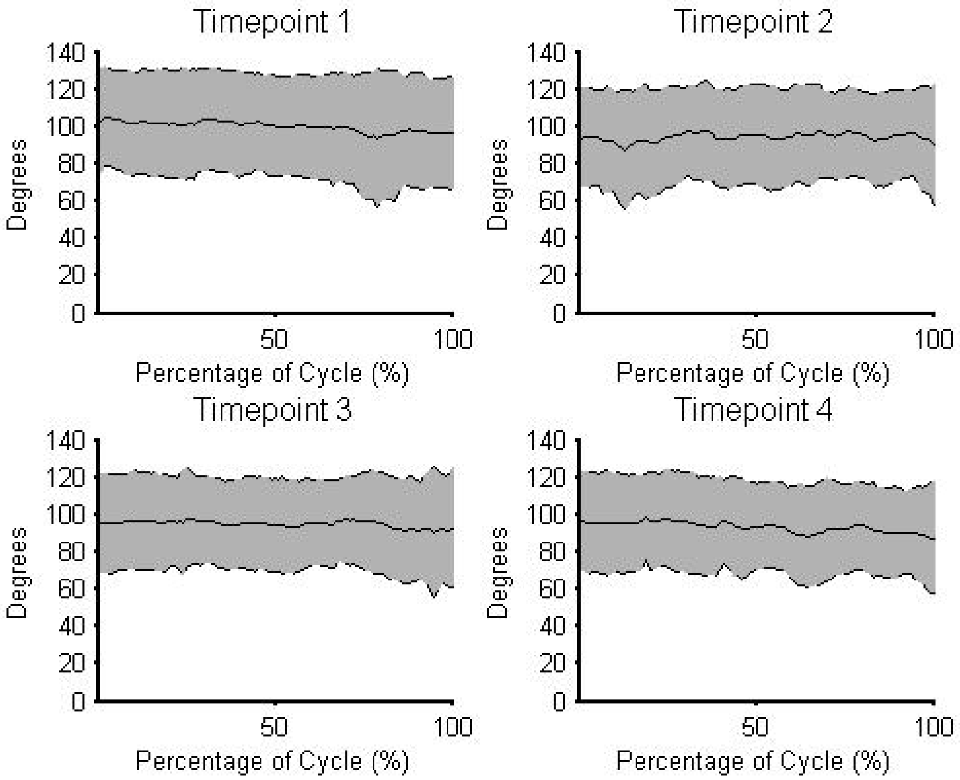


Figure D52: Mean right thoracohumeral +abduction/-adduction kinematic profiles, with +/- one standard deviation, for the Overhead Work task.

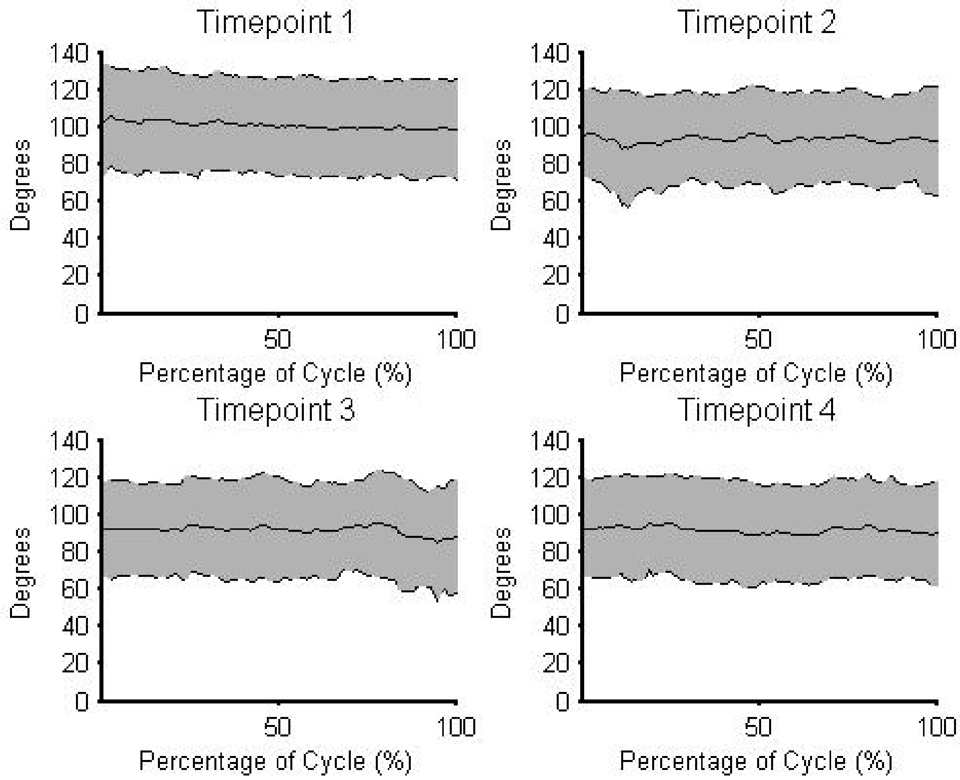


Figure D53: Mean left thoracohumeral +abduction/-adduction kinematic profiles, with +/- one standard deviation, for the Overhead Work task.

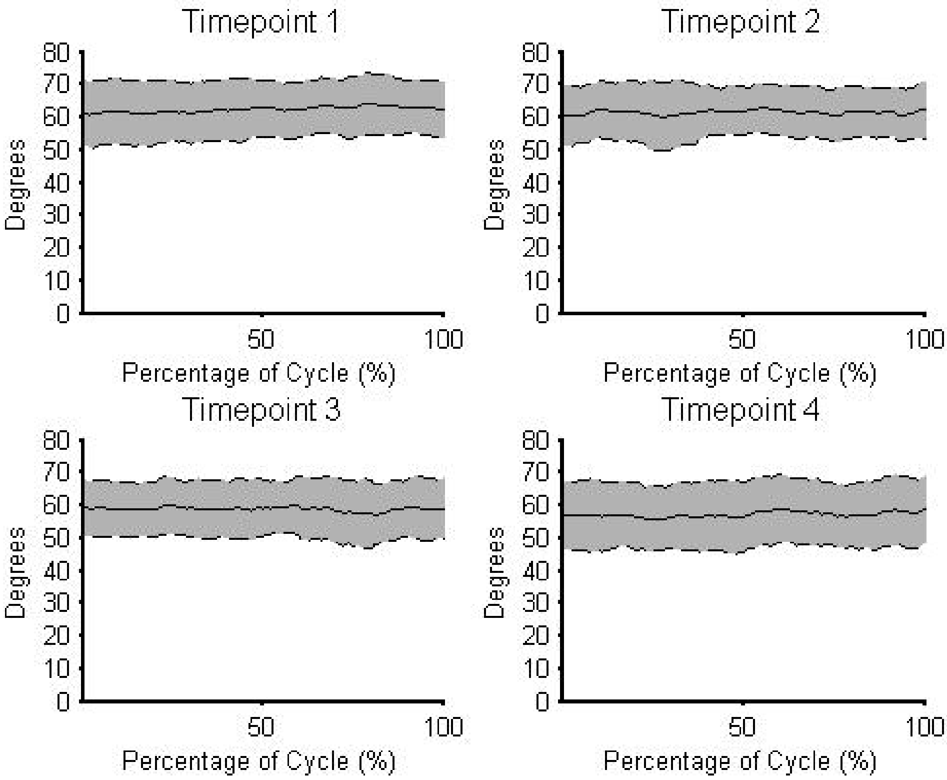


Figure D54: Mean right thoracohumeral +flexion/-extension kinematic profiles, with +/- one standard deviation, for the Overhead Work task.

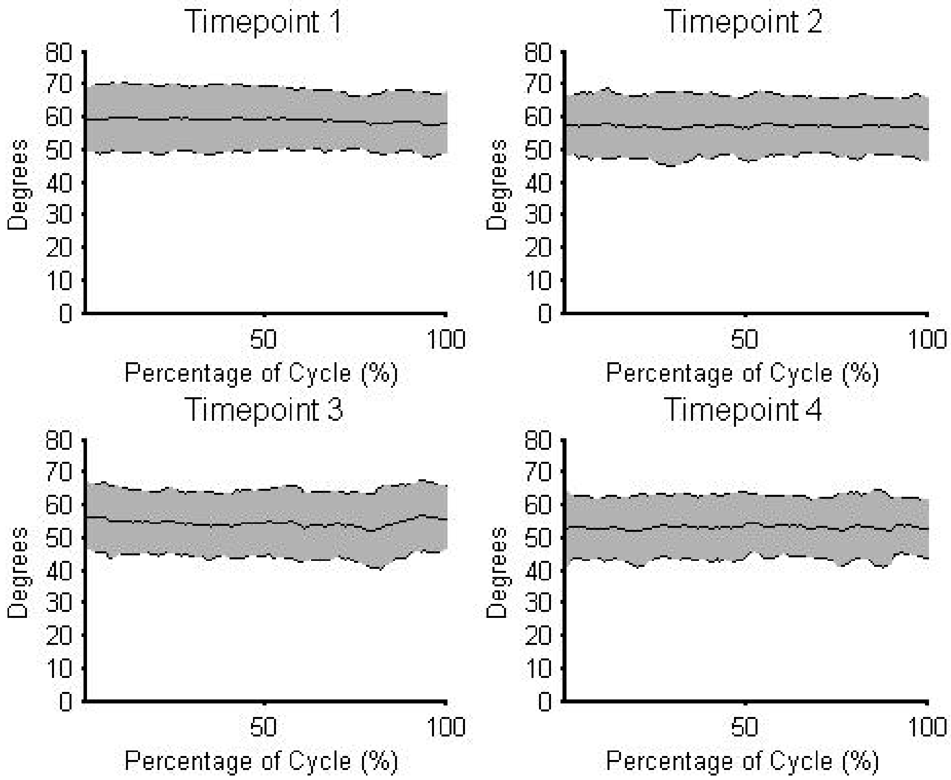


Figure D55: Mean left thoracohumeral +flexion/-extension kinematic profiles, with +/- one standard deviation, for the Overhead Work task

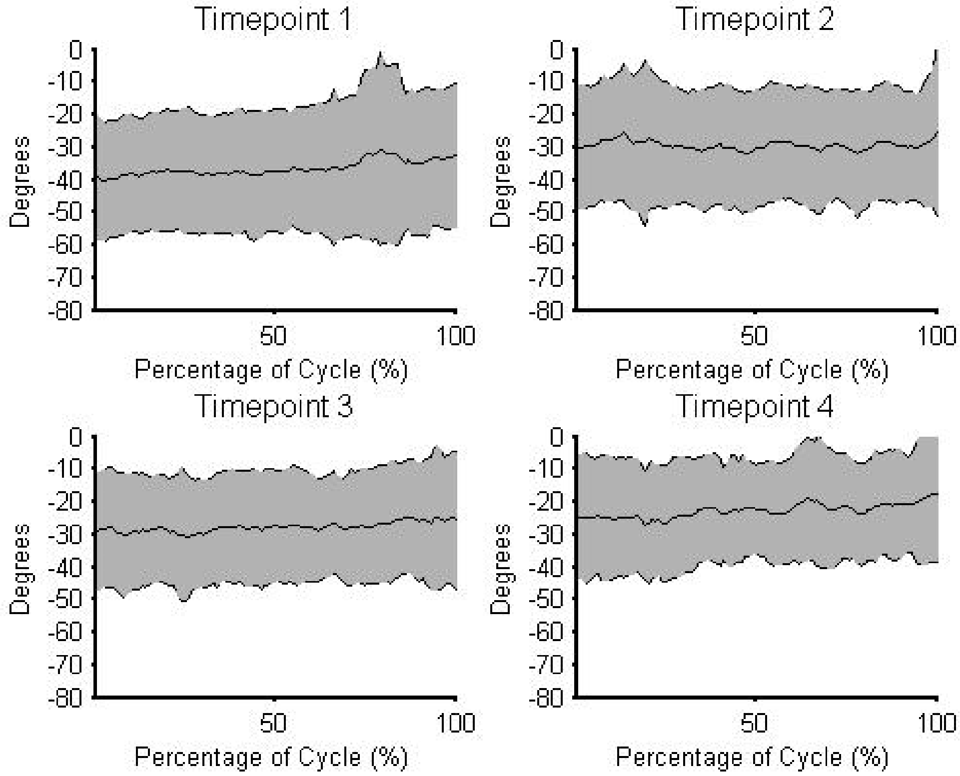


Figure D56: Mean right thoracohumeral +internal/-external axial rotation kinematic profiles, with +/- one standard deviation, for the Overhead Work task.

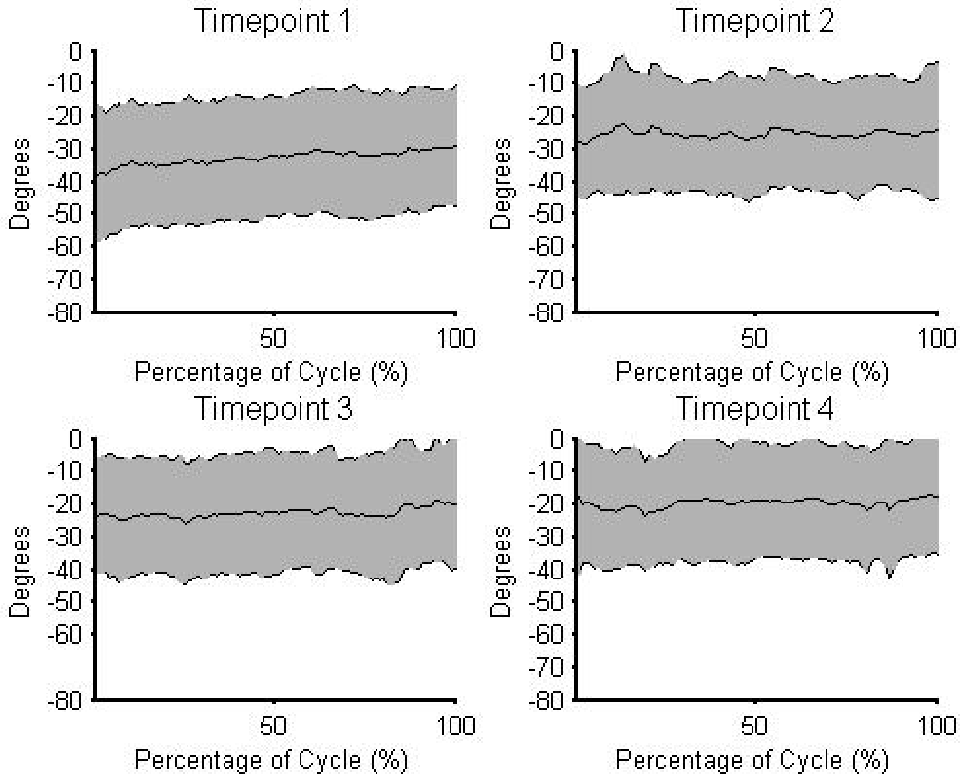


Figure D57: Mean left thoracohumeral +internal/-external axial rotation kinematic profiles, with +/- one standard deviation, for the Overhead Work task.

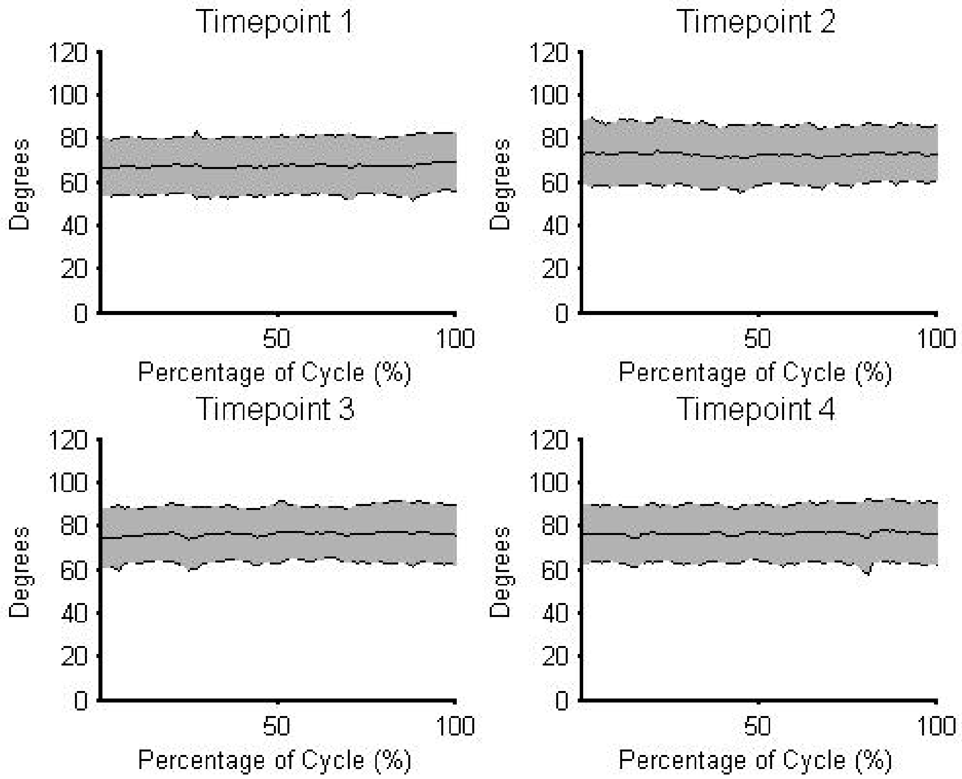


Figure D58: Mean right elbow +flexion/-hyperextension kinematic profiles, with +/- one standard deviation, for the Overhead Work task.

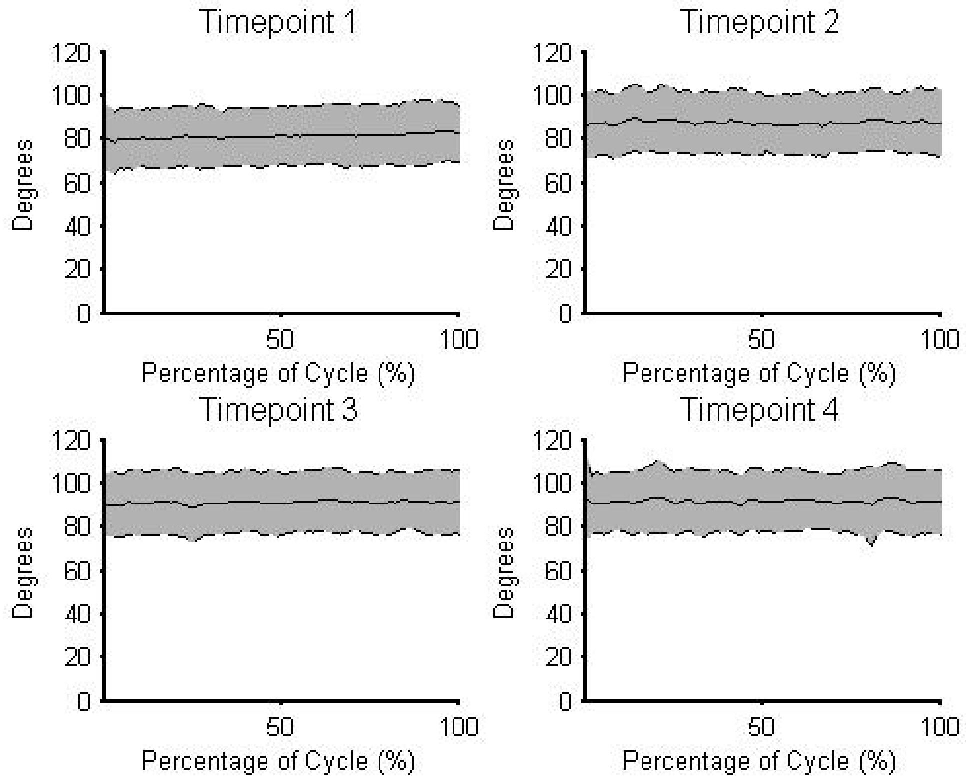


Figure D59: Mean left elbow +flexion/-hyperextension kinematic profiles, with +/- one standard deviation, for the Overhead Work task.

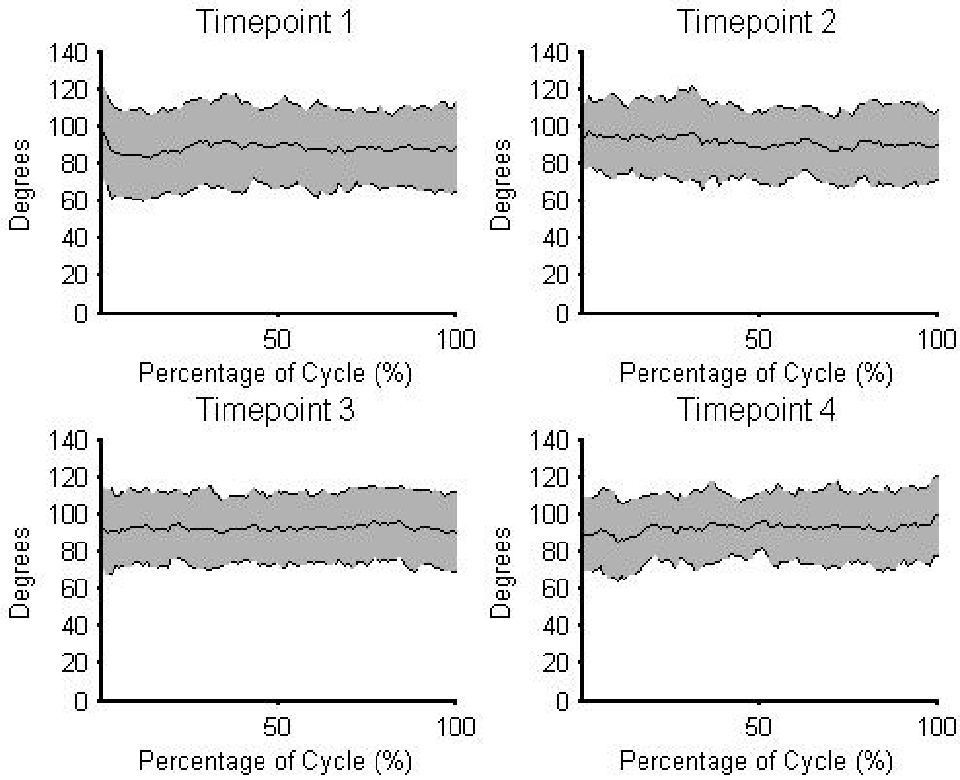


Figure D60: Mean right elbow +pronation kinematic profiles, with +/- one standard deviation, for the Overhead Work task.

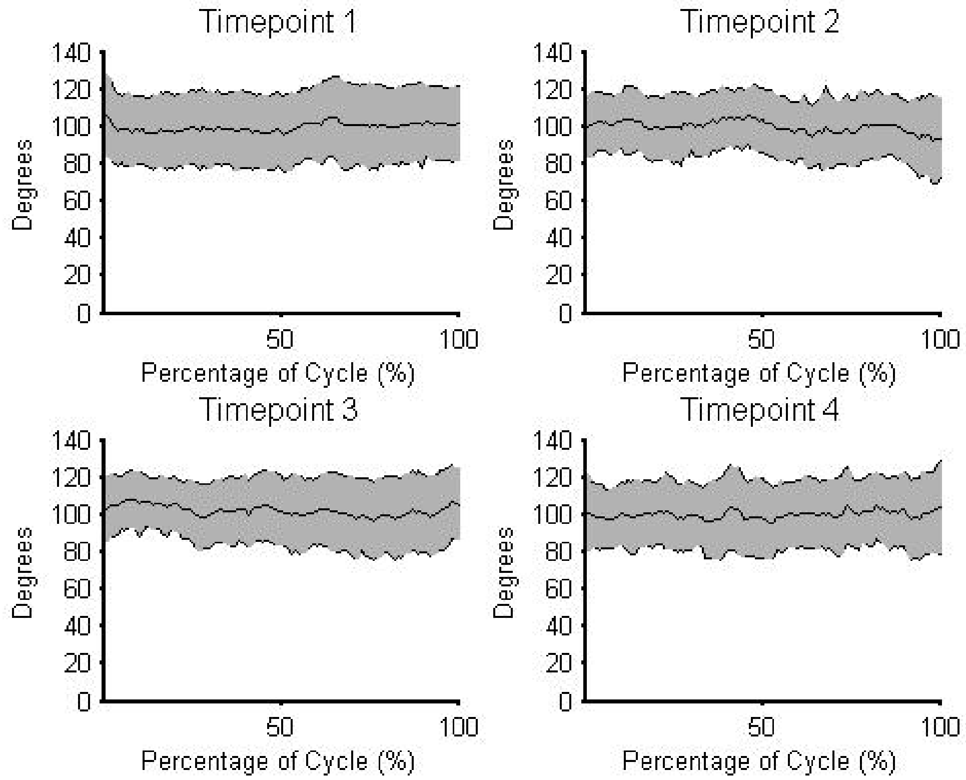


Figure D61: Mean left elbow +pronation kinematic profiles, with +/- one standard deviation, for the Overhead Work task.

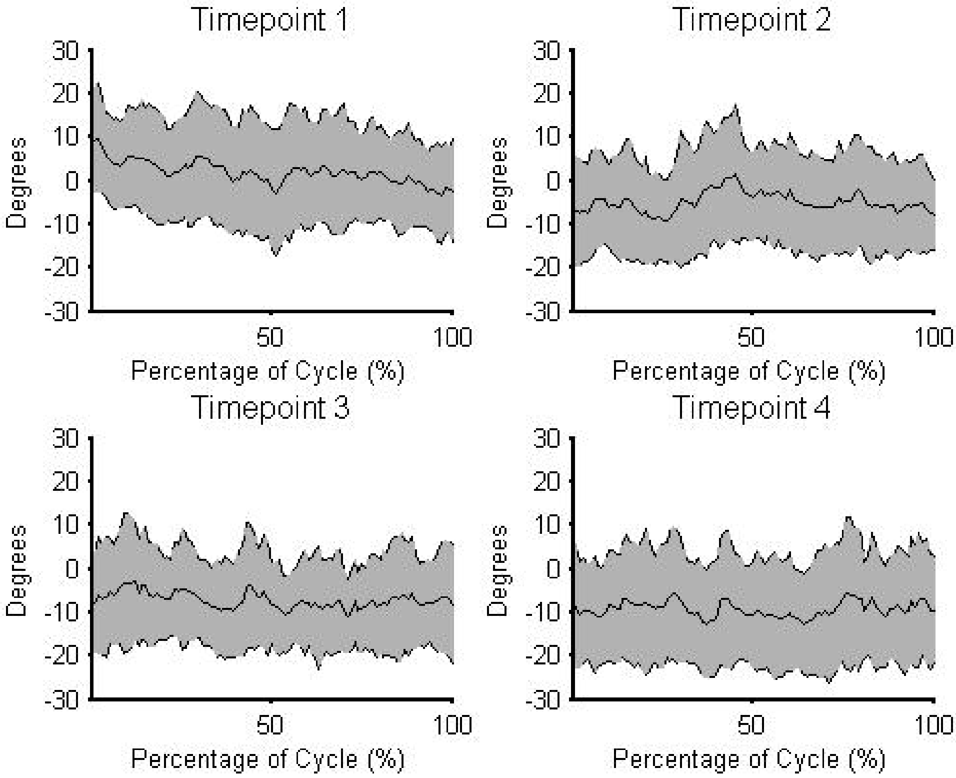


Figure D62: Mean right wrist +flexion/-extension kinematic profiles, with +/- one standard deviation, for the Overhead Work task.

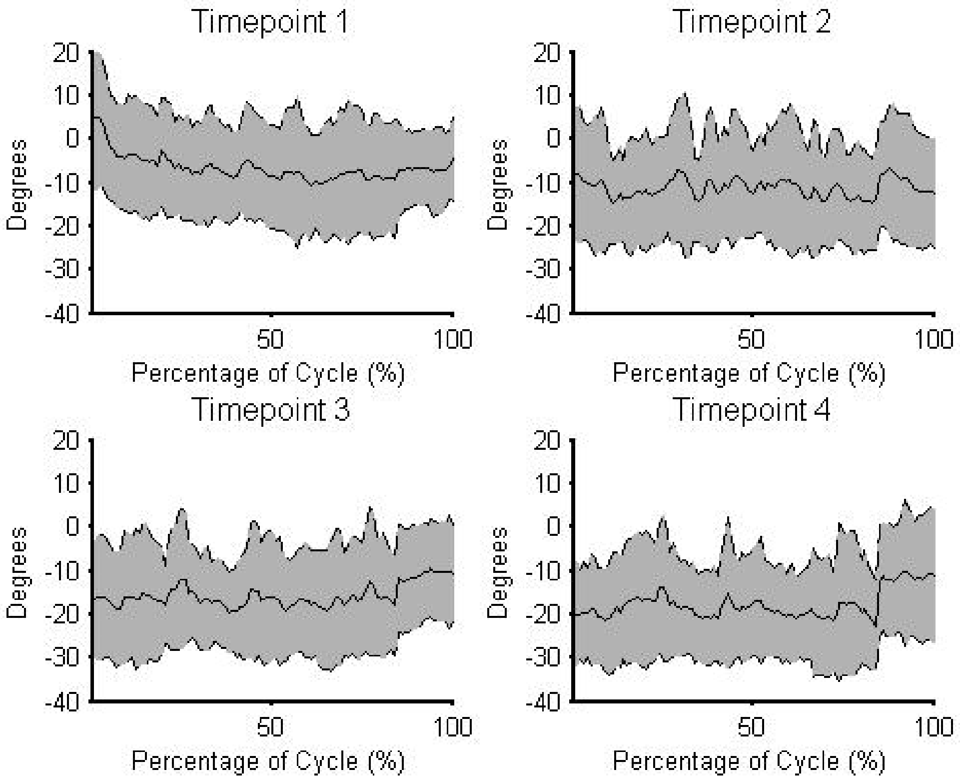


Figure D63: Mean left wrist +flexion/-extension kinematic profiles, with +/- one standard deviation, for the Overhead Work task.

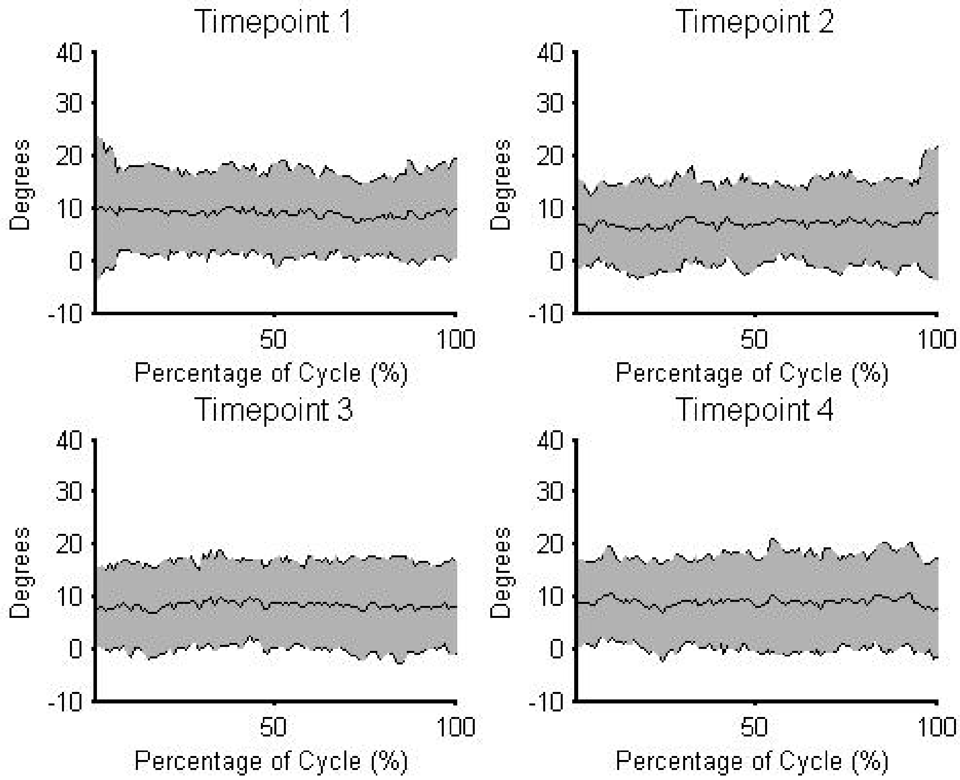


Figure D64: Mean right wrist +ulnar/-radial deviation kinematic profiles, with +/- one standard deviation, for the Overhead Work task.

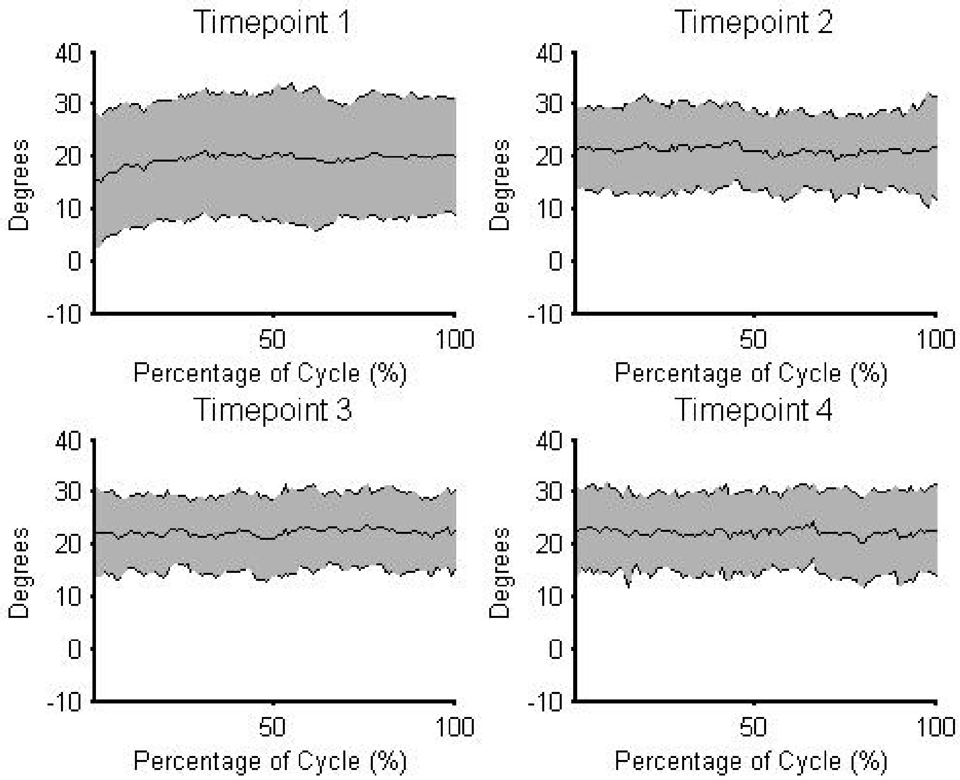


Figure D65: Mean left wrist +ulnar/-radial deviation kinematic profiles, with +/- one standard deviation, for the Overhead Work task.