Lumbar Spine and Hip Kinematics and Muscle Activation Patterns during Coitus: A comparison of common coital positions

by

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Author's Declaration

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

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Natalie Sidorkewicz

Abstract

Qualitative studies investigating the sexual activity of people with low back pain found a substantial reduction in the frequency of coitus and have shown that pain during coitus due to mechanical factors (i.e., movements and postures) are the primary reason for this decreased frequency. However, a biomechanical analysis of coitus has never been done. The main objective of this study was to describe male and female lumbar spine and hip motion and muscle activation patterns during coitus and compare these motions and muscle activity across five common coital positions. Specifically, lumbar spine and hip motion in the sagittal plane and electromyography signal amplitudes of selected trunk, hip, and thigh muscles were described and compared. A secondary objective was to determine if simulated coitus could be used in place of real coitus for future coitus biomechanics research.

Ten healthy males (29.3 ± 6.9 years, 176.5 ± 8.6 centimeters, 84.9 ± 14.5 kilograms) and ten healthy females (29.8 ± 8.0 years, 164.9 ± 3.0 centimeters, 64.2 ± 7.2 kilograms) were included for analysis in this study. These couples had approximately 4.7 ± 3.9 years of sexual experience with each other. This study was a repeated-measures design, where the independent variables, coital position and condition, were varied five (i.e., QUADRUPED1, QUADRUPED2, MISSIONARY1, MISSIONARY2, and SIDELYING) and two (i.e., real and simulated) times, respectively. Recruited participants engaged in coitus in five pre-selected positions (presented in random order) for 20 seconds per position first in a simulated condition, and again in a real condition. Three-dimensional (3D) lumbar spine and hip kinematic data were continuously collected for the duration of each trial by optoelectronic and electromagnetic motion capture systems. Electromyography (EMG) signals were also continuously collected for the duration of each trial. The kinematic data and EMG signals were collected simultaneously for both participants. Five sexual positions were chosen for this study based on the findings of previous literature and a biomechanical rationale. QUADRUPED – rear-entry, female quadruped, male kneeling behind – had two variations; in QUADRUPED1 the female was supporting her upper body with her elbows and in QUADRUPED2 the female was supporting her upper body with her hands. MISSIONARY – front-entry, female supine, male prone on top – also had two variations; in MISSIONARY1 the female was not flexing her hips or knees and the male was supporting his upper body with his hands, but in MISSIONARY2, the female was flexing her hips and knees and the male was supporting his upper body with his elbows. SIDELYING – rear-entry, female side-lying on her left side, male side-lying behind – did not have any variations. To determine if each coital position had distinct spine and hip kinematic and muscle activation profiles, separate univariate general linear models (GLM) (factor: coital position = five levels, α=0.05) followed by Tukey's honestly significant difference (HSD) post hoc analysis were used. To determine if simulated coitus was representative of real coitus across all spine and hip kinematic and muscle activation outcome variables, paired-sample t-tests (α=0.05) were performed on all outcome variables for the real condition and their respective simulated values.

In general, the coital positions studied showed that, for both males and females, coitus is mainly a flexion-extension movement of the lumbar spine and hips. Males used a greater range of their spine and hip motion in comparison to females. As expected, differences were found between coital positions for males and females and simulated coitus was not representative of real coitus, in particular the spine and hip kinematic profiles. The results found in this biomechanical analysis of common coital positions may be useful in a clinical context. It is

recommended that during the acute stage of a low back injury resulting in flexion-, extension-, or motion-intolerance that coitus be avoided. If the LBP is a more chronic issue, particular common coital positions should be avoided. For the flexion-intolerant male patient, avoid SIDELYING and MISSIONARY2 as they were shown to require the most flexion. Both variations of QUADRUPED are the more spine-sparing of coital positions followed by, MISSIONARY1. Coaching the male patient on proper hip-hinging technique while thrusting – an easy technique to incorporate in both variations of QUADRUPED – will likely decrease spine movement and increase the spine-sparing quality of QUADRUPED. For the flexion-intolerant female patient, avoid both variations of MISSIONARY, especially with hip and knee flexion, as they were shown to elicit the most spine flexion. QUADRUPED2 and SIDELYING are the more spine-sparing coital positions, followed by QUADRUPED1. Subtle posture changes for a coital position should not be considered lightly; seemingly subtle differences in posture can change the spine kinematic profile significantly, resulting in a coital position that was considered spine-sparing becoming a position that should be avoided.

Thus, spine-sparing coitus appears to be possible for the flexion-, extension-, and motion-intolerant patient. Health care practitioners may recommend appropriate coital positions and coach coital movement patterns, such as speed control and hip-hinging. With respect to future research in the area of sex biomechanics, using simulated coitus in replace of real coitus is not justifiable according to the data of this study. However, including a simulated condition did prove beneficial for increasing the comfort level of the couples and allowing time to practice the experimental protocol. Future directions may address female-centric positions (e.g., ‘reverse missionary’ with male supine and female seated on top), and back-pained patients with and without an intervention (e.g., movement pattern coaching or aides, such as a lumbar support).

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had in the purpose of my work. Because of you, partners may find intimacy again and new conversations will be starting between low back pained patients and their health care practitioners.

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Dedication

This work is dedicated to the many couples who are struggling to maintain their intimacy because of chronic LBP – may this help to raise your voices with your health care providers and each other – and to the health care practitioners who treat them – may this first step be a helpful tool.

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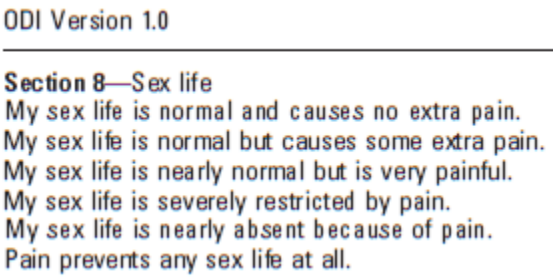
Chapter 1
Introduction

1.1 Rationale

In their lifetime, up to eighty percent of people will have experienced at least one episode of low back pain (LBP) (Statistics Canada [updated 2006]). Several qualitative studies investigating the sexual activity of people with low back pain and/or injury have consistently found a substantial reduction in the frequency of coitus after the onset of LBP and have shown that pain during coitus due to mechanical factors, such as movements and postures, are reported as the primary reason for the decreased frequency of coitus than psychological factors (e.g., fear-avoidance) (see below for a summary of the findings of Akbas and colleagues (2010), Berg and colleagues (2009), Maigne and Chatellier (2001), Osborne and Maruta (1980), and Sjögren and Fugl-Meyer (1981)).

This reduction in the frequency of sexual activity in people with low back pain and/or injury has important implications for their quality of life (QoL) and health and disability. Sexual activity is a known indicator of QoL (Stock et al. 1996) and is incorporated into one of the most commonly recommended condition-specific outcome measures for spinal disorders: the Oswestry Disability Index (ODI). The American Academy of Orthopaedic Surgeons (AAOS) and other spine societies have adapted ODI Version 1.0 (Fairbank et al. 1980) into their spine outcome instruments (Fairbank & Pynsent 2000), which includes an item regarding sex life in its measure of disability (Fig. 1).


ODI Version 1.0

Section 8—Sex life
My sex life is normal and causes no extra pain.
My sex life is normal but causes some extra pain.
My sex life is nearly normal but is very painful.
My sex life is severely restricted by pain.
My sex life is nearly absent because of pain.
Pain prevents any sex life at all.

Fig. 1. Excerpt from the ODI Version 1.0 highlighting an item regarding sex life in its measure of disability.
(Fairbank et al. 1980).

Furthermore, the World Health Organization's (WHO) International Classification of Functioning, Disability, and Health (ICF, World Health Organization [updated 2001]) regards sexual relationships – creating and maintaining a relationship of a sexual nature, with a spouse or other partner – as an integral factor in the international standard to describe and measure health and disability (World Health Organization [updated 2001]).

Despite consistent reports of a reduction in the frequency of sexual activity primarily due to mechanical factors after the onset of low back pain and/or injury, a biomechanical analysis of basic coital positions has not been conducted (White & Panjabi 1990). Understanding lumbar spine and hip movement characteristics and muscle activation patterns during common sexual positions may result in a

biomechanical rationale to explain these reports and generate recommendations for modifying sexual positions with the intention of decreasing the likelihood of exacerbating low back pain and/or injury during coitus and consequently improving the frequency of sexual activity, the maintenance of sexual relationships, and, ultimately, the quality of life and health of those suffering from low back pain and injury.

1.2 Purpose

Since a biomechanical analysis of common sexual positions has never been performed, the nature of this study was primarily descriptive. The main objective of this study was to describe the three-dimensional (3D) movement and posture characteristics and muscle activation patterns of the lumbar spine and hips during coitus, and compare these characteristics and patterns between five common coital positions. Specifically, 3D angular displacement of the lumbar spine and hips and electromyography (EMG) signal amplitudes of selected trunk, hip, and thigh muscles was described and compared. A secondary objective was to determine if simulated coitus could be used in place of real coitus for future sex biomechanics research.

1.3 Hypotheses

Regardless of the descriptive nature of this study, hypotheses can be formed regarding expected observations. Specifically, it was expected that movement of the spine and hips would primarily occur in the sagittal plane of motion (i.e., flexion-extension). For both males and females, it was hypothesized that each coital position would have distinct spine and hip kinematic profiles, with the exception of the two variations of female QUADRUPED, male kneeling behind, for the males. For males, distinct muscle activation profiles were expected across all coital positions, but not for females. Since males and females assumed entirely different postures within each coital position, they were considered separate groups in the subsequent data analysis to test these hypotheses.

It was hypothesized that simulated coitus would not be representative of real coitus across all spine and hip kinematic variables and muscle activation outcome variables of the trunk musculature.

Chapter 2
Literature Review

A review of the findings of limited qualitative studies investigating the sexual activity of people with low back pain and/or injury are discussed below followed by a biomechanical rationale that supports the need for this proposed investigation and provides guidance for the study design and methodology.

2.1 Qualitative research on sexual activity and low back pain and/or injury

2.1.1 Frequency reduction

Several studies evaluating self-reports of the sexual activity of people before and after the onset of low back pain and/or injury have shown a reduction in frequency of coitus after the onset for the majority of these people. Akbas and colleagues (2010) evaluated sexual problems and sexual behaviour patterns before and after surgery in a group of patients with lumbar disc herniation and found that frequency of sexual intercourse before the operation was reduced in 78 percent of the patients (84 percent of the men and 73 percent of the women) at the time of diagnosis compared with the period when patients had been pain free. When comparing frequency of sexual intercourse postoperatively to preoperatively, men and women reported a 27 and 10 percent decrease in 'two to five times per week', a 24 and 5 percent increase in 'once per week', and a 7 percent decrease and 5 percent increase in 'more rarely than once a week', respectively (Akbas et al. 2010).

Osborne and Maruta's (1980) study of the sexual activity of married patients referred to a pain management center revealed similar results; approximately 66 percent of the patients reported a reduction in the frequency of sexual activity after the onset of LBP (Osborne & Maruta 1980). Furthermore, a questionnaire-based study assessed the sexual activity of patients with LBP compared to a control group and found that 55 percent of women and 34 percent of men were having intercourse less frequently – 74 and 50 percent of the women and men had intercourse an average of less than five times per month, respectively (Maigne & Chatellier 2001). Sjögren and Fugl-Meyer (1981) conducted structured interviews to investigate sexuality in males and females with chronic LBP and found that in approximately 50 percent of studied cases, frequency of coitus decreased from one to two times per week (the median frequency of coitus before disablement) and some subjects had to cease intercourse completely (Sjögren & Fugl-Meyer 1981).

2.1.2 Postures and movements attributed

These qualitative studies on sexual activity of people before and after the onset of low back pain and/or injury call attention to a common problem among this population, but the factors attributed to the reduced frequency of coitus are also important to understand. Qualitative studies have consistently shown that pain or discomfort during coitus due to mechanical factors, such as movements and postures, are reported to be the primary reason for the decreased frequency of coitus rather than psychological factors (e.g., fear-avoidance). Sex life was reported as causing additional pain in 84 percent of patients with chronic LBP (of assumed discogenic origin considered for surgical treatment) – 34 percent experienced 'some' pain,

20 percent found sex ‘very painful’, and 30 percent reported that their sex life was ‘severely restricted’ due to pain or that pain ‘prevent[ed] any sex life at all’ (Berg et al. 2009). At a two-year post-operative follow-up, sex life had improved and this improvement was correlated strongest with a decrease in back pain (measured by visual analog scale [VAS]) and an improvement regarding global assessment of back pain (Berg et al. 2009).

Other studies have specifically indicated pain during coital postures and movements as the primary reason for reduction in coitus. For example, 58 percent of women and 22 percent of men with LBP reported marked discomfort during intercourse in a questionnaire-based study (Maigne & Chatellier 2001). Of these men and women, two of the most commonly reported problems experienced when having sex were attributed to postures and movements assumed during coitus: difficulty finding a position and difficulty with pelvic movements (Maigne & Chatellier 2001). Structured interviews of males and females with chronic LBP revealed similar attributes; after the onset of disabling LBP, the type of positions used were changed because of the back pain (Sjögren & Fugl-Meyer 1981). Thus, it can be assumed that certain postures were too painful to maintain, especially since patients also disclosed that one of the important factors that restricted sexual enjoyment was the back pain itself (Sjögren & Fugl-Meyer 1981). The subjective findings of these studies provide valuable insight into this common problem among back pain and injury sufferers – mechanical factors, such as movements and postures during coitus, exacerbate LBP, which results in a reduced frequency of sexual activity.

2.1.3 Self-reported most and least comfortable coital positions

In current literature, self-reports on the most and least painful coital positions show similar trends among males and females. In Maigne and Chatellier’s (2001) questionnaire-based study that assessed the sexual activity of patients with LBP compared to a control group, males and females were asked to report on the most and least painful coital positions. Both males and females reported the prone position as the most painful coital position (59% male, 48% female) (Maigne & Chatellier 2001); only six percent of females and no males reported prone as the least painful coital position (Maigne & Chatellier 2001). Agreement was also found between genders for the least painful coital positions; more males and females reported supine as the least painful (78% and 58%, respectively) than most painful (3% and 23%, respectively) coital position followed by side-lying (22% of males and 26% of female report least painful versus 16% of males and 19% of females report most painful) (Maigne & Chatellier 2001). An equal number of females (10%) reported the ‘squatting over the partner’ coital position to be the most and least painful (Maigne & Chatellier 2001). No female respondents reported ‘no painful position’, but 22 percent of the males did (Maigne & Chatellier 2001).

Sjögren and Fugl-Meyer’s (1981) structured interviews of males and female with chronic LBP revealed similar trends between genders: males employed the prone position 26 percent less after the onset of chronic LBP followed by side-lying (9% less), ‘other’ (6% less), and did not report a change in employment of the supine position, which implies that prone was the most painful and supine was the least painful coital position. Females reported employing the side-lying position 12 percent less after the onset of chronic LBP followed by supine and prone positions (8% less), and ‘other’ (4% less).

A biomechanical analysis of movements and postures during basic coital positions would likely help to rationalize these reports. Although a biomechanical analysis of sexual positions has not been conducted

(White & Panjabi 1990), Osborne and Maruta (1980) and White and Panjabi (1990) have employed a basic biomechanical rationale to provide recommendations to those suffering from low back pain and/or injury of coital positions that would put as little strain on the back as possible. Both authors deduced that a side-lying sexual position (assumed by both partners) would be the ideal basic position when experiencing LBP (Osborne & Maruta 1980; White & Panjabi 1990).

2.1.4 Limitations of the qualitative research on sexual activity and low back pain and/or injury

The findings of the above qualitative studies are limited in their interpretation due to the lack of recognition that LBP is not a homogeneous disorder. For example, an extension-intolerant LBP patient (e.g., facet joint injury) may find a prone coital position very painful whereas a flexion-intolerant patient (e.g., disc herniation injury) may find the same prone coital position the most comfortable and a motion-intolerant patient may find all coital positions painful. Mechanical factors contributing to LBP during coital movements and postures will vary depending on the individual's low back disorder. The assumption of generic LBP is limited in directing discussion of the mechanical factors contributing to LBP during coital movements and postures.

2.2 Biomechanical rationale for subjective findings

2.2.1 Magnetic resonance imaging (MRI) of coitus

The anatomy of sexual intercourse has been studied using magnetic resonance imaging (MRI) in the reverse missionary position (i.e., front-entry, male lying supine and female on top) (Faix et al. 2001; Schultz et al. 1999), missionary position (i.e., front-entry, female lying supine and male on top) and rear-entry position (i.e., rear-entry, female lying prone with buttocks slightly turned upward and male on top) (Faix et al. 2002). Although the focus of these studies was not on the vertebral bodies or intervertebral discs of the lumbar spine, midsagittal MRI images presented in consecutive order (New Scientist [updated 2009]) show the inherent repetitive flexion-extension movement of coitus (Fig. 2 is meant to orient the reader and Fig. 3 is intended to show the flexion-extension motion during one penetration cycle of coitus).

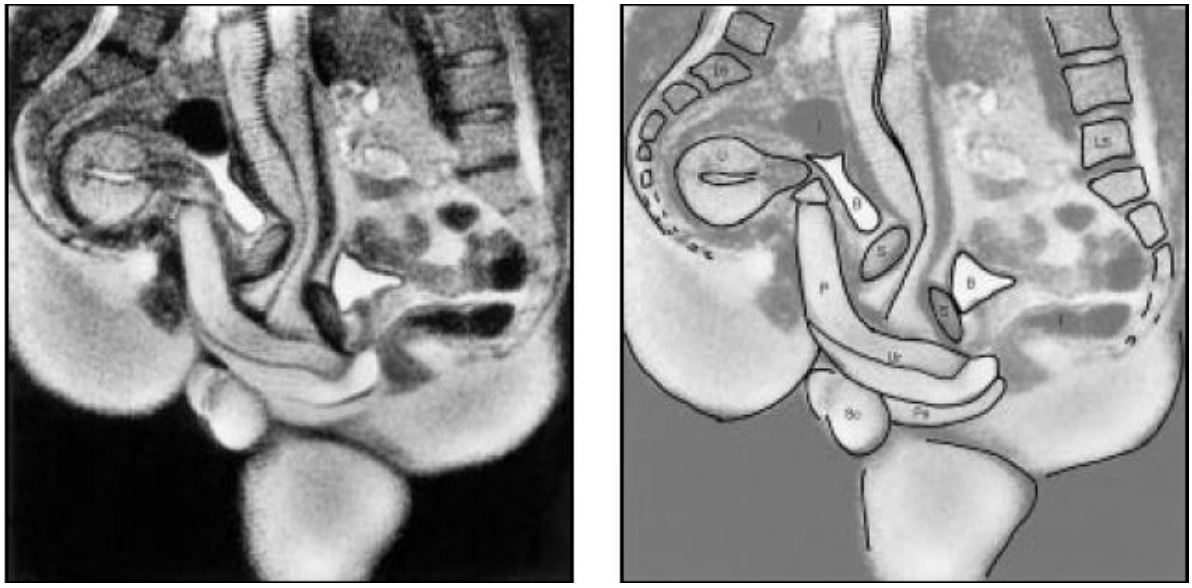


Fig. 2. Midsagittal MRI image of the anatomy of sexual intercourse.
(Schutlz et al. 1999). The following abbreviation key is meant to orient the reader: P = penis, Ur = urethra, Pe = perineum, U = uterus, S = symphysis, B = bladder, I = intestine, L5 = lumbar, Sc = scrotum

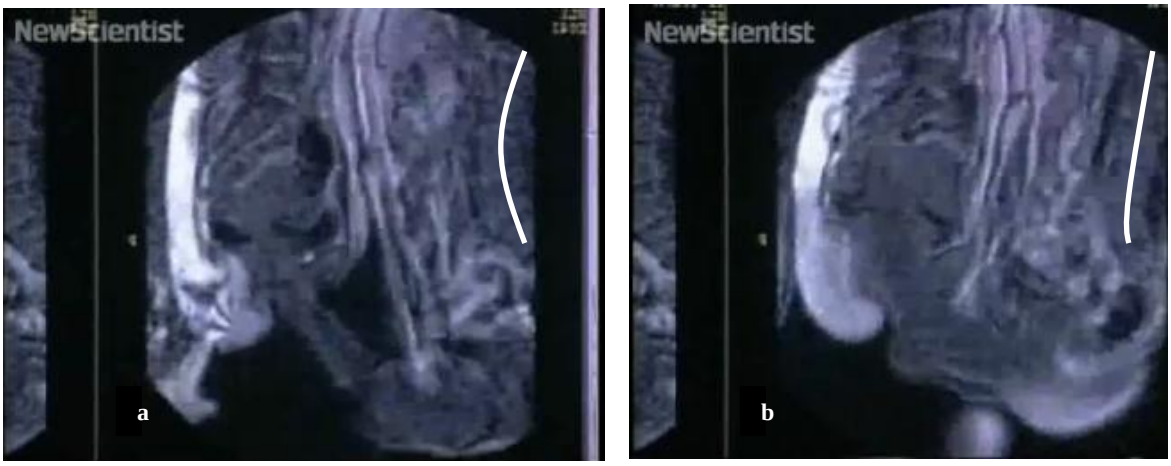


Fig. 3. Midsagittal MRI image of the anatomy of sexual intercourse at the beginning (a) and end (b) of the penetration cycle.
(New Scientist [updated 2009]). Note the white line, which roughly estimates lumbar spine curvature at the beginning (more extended) and end (more flexed) of the penetration cycle.

For this reason, the following discussion will focus on flexion-extension movement and flexed and extended postures.

2.2.2 Biomechanical response and failure mechanics of lumbar spine motion segments

2.2.2.1 Movements and postures

The biomechanical response and failure mechanics of lumbar spine motion segments during flexion and extension support the findings from the qualitative research on sexual activity of people with low back pain and/or injury that decreased frequency of coitus is primarily attributed to an increase in pain during coital postures and movements.

Highly repetitive lumbar spine flexion and extension – motions inherent to coitus – has been shown to consistently produce herniation in non-degenerated, controlled porcine spine motion segments, with relatively low magnitude compressive joint forces (i.e., 867 and 1472 N) (Callaghan & McGill 2001). Although these failure mechanics were reported in porcine spine motion segments, Fennell and colleagues (1996) found that the nucleus tends to migrate within the disc in the same manner that it migrates in cadaveric specimens in their investigation of the migration of the nucleus pulposus within the intervertebral disc during flexion and extension of the lumbar spine *in vivo*; during flexion, the nucleus tends to migrate posteriorly and during extension it tends to migrate anteriorly and the extent of this migration is correlated with the flexion-extension angle (Fennell at al. 1996). The effects of these migration patterns during flexion and extension on nerve root compression in human cadaveric specimens induced with disc herniations were reported by Schnebel and colleagues (1989). Flexion of the lumbar spine increased and extension decreased the compressive force on the fifth lumbar nerve root (Schnebel et al. 1989).

Furthermore, an investigation of the effect of posture (i.e., flexed versus neutral) on the compressive strength and site of failure in the spine revealed that both ultimate compressive strength and yield point were reduced when loading to failure was performed in a flexed versus neutral posture (Gunning et al. 2001; Yingling & McGill 1999); full flexion reduces the ability of the spine to bear compressive load and the way in which the tissues of the spine fail (Gunning et al. 2001).

2.3 Summary

Considering that a reduction in frequency of coitus has been shown to be common among people with LBP and primarily attributable to mechanical factors, a biomechanical analysis of coitus is pertinent. A quantitative study describing and comparing the 3D movement and posture characteristics and muscle activation patterns of the lumbar spine and hips in coital positions will contribute to the understanding of the fundamental lumbar spine and hip biomechanics of coitus.

This biomechanical analysis may also be useful in a clinical setting. Many health care practitioners (HCPs), such as physiotherapists, feel uncomfortable discussing their client's sexual needs (Pynor et al. 2005) or do not address them at all. Any recommendations that HCPs do currently provide are based on conjectures, clinical experience (Rubin 1970), or popular media resources (see Hebert 1987 and White 1990 for examples). Their recommendations cannot be qualified with empirical data because, to date, a quantitative analysis of coitus has not been conducted (White & Panjabi 1990). Providing HCPs with insight into the lumbar spine and hip biomechanics of coitus will qualify their recommendations to patients with LBP on modifying their sexual activity with empirical data. With a better understanding of

the biomechanics of coitus, coital movements and postures can be appropriately modified for a person with LBP, which would reduce their likelihood of exacerbating their injury, improve their likelihood of maintaining frequency of sexual activity and sexual relationships, and consequently improve their quality of life and health.

Chapter 3
Methodology

The data collections were conducted in the Spine Biomechanics Laboratory (BMH 1407/1408) at the University of Waterloo. The duration of each data collection ranged from approximately two and one half to four hours. After set up was complete, participants engaged in simulated and real coitus in five pre-selected coital positions (presented in a random order) while lumbar spine and hip kinematics and muscle activity were simultaneously recorded. **All subject recruitment and data collection procedures were performed in accordance with University of Waterloo's Office of Research Ethics guidelines.**

3.1 Participants

Ten healthy males (29.3 ± 6.9 years, 176.5 ± 8.6 centimeters, 84.9 ± 14.5 kilograms) and ten healthy females (29.8 ± 8.0 years, 164.9 ± 3.0 centimeters, 64.2 ± 7.2 kilograms) were included for analysis in this study. These couples had approximately 4.7 ± 3.9 years of sexual experience with each other.

3.1.1 Inclusion criteria

Couples were considered for inclusion in this study if they were heterosexually-oriented, aged 23 to 50, and in a committed relationship with a minimum of one year of sexual experience with each other. The selected age range was based on the most 'at-risk' age group for lumbar spine intervertebral disc herniations – one of the most common low back injuries and causes of LBP. Furthermore, according to the directive of the Office of Research Ethics, undergraduate-aged adults were not included in this study. The inclusion of couples in a committed relationship with a minimum one-year history of sexual experience with each other was to ensure that each participant felt as comfortable, and able to move as naturally, as possible during the data collection.

3.1.2 Exclusion Criteria

Couples were not considered for participation in this study if any of the following criterion were satisfied: (1) heart condition that was treated in the past or currently being treated; (2) a history of spinal, abdominal, or hip surgery; (3) a pre-existing disabling back or hip condition; (4) current and relevant musculoskeletal concerns; (5) sexual dysfunctions that would prevent engaging in coitus for the duration of the data collection (e.g., erectile dysfunction and premature ejaculation would meet this exclusion criterion, whereas orgasmic dysfunction may still be included in this study); (6) allergies to ethanol, skin adhesives, conductance gels, or silver-based products; (7) current University of Waterloo graduate student in the Department of Kinesiology; or (8) undergraduate student at the University of Waterloo in any department.

3.1.3 Pre-study Interview

If couples met the inclusion criteria for this study, they were invited to the laboratory for a pre-study interview to confirm eligibility. If they were unable to visit the laboratory prior to the data collection, the pre-study interview was conducted via telephone or videoconference. The purpose of this interview was

to help the researcher assess each potential participant's eligibility for inclusion in this study, comfort level with study participation, and thoughts and feelings regarding the possible scenario where they or their partner no longer wished to participate and withdrew consent during the data collection – how they would convey this desire and how they think they or their partner and the researcher would respond. This and other scenarios were addressed with direct questions within the pre-screening interview questionnaire as well as other questions that probed for possible power imbalances in the potential participant's relationship with their partner. The pre-study interview questionnaire was developed in collaboration with a local expert in power imbalances in relationships and adapted from some of their previous work – this consultant is a former lecturer at Wilfred Laurier University, a clinician in private practice for clients with sexuality issues and other psychological problems, and an educator and advocate for recognition of wife abuse, power imbalances in relationships and feminist approaches to counseling.

The impression of a power imbalance in a relationship was not formed based off of a single response to a question during the interview, rather if a pattern of responses emerged. For example, if potential participants responded to Question 3 of the pre-screening interview (see Appendix A) (i.e., "When you and your partner disagree, how do you resolve the conflict?") by saying that they or their partner yell or shout, call names, say unkind things, etc. when they resolve a conflict, the researcher would recognize this as a less desirable response and would evaluate this response in conjunction with the other pre-screening interview question responses to detect a possible power imbalance in the relationship. If all other responses did not support the notion that the relationship had a power imbalance, the potential participant and their partner would still be considered for participation in the study. If, however, other question responses, such as Question 6 (i.e., "If, in the middle of the study, you decided that you no longer wanted to participate and wanted to withdraw your consent, would you let your partner know? How would you convey this? You know your partner very well. What do you think their response would be? What do you think the researcher's response would be?") or Question 7 (i.e., "If the roles were reverses and it was your partner that no longer wanted to participate and wanted to withdraw consent, how would you respond?") were also problematic responses, then the potential participant and their partner would be excluded from the study. Potentially problematic responses to Question 6 would include, the potential participant stating that they would not feel comfortable letting their partner know that they wanted to withdraw consent and/or feeling that their partner's and/or the researcher's response would be unsupportive or not accepting of their wish to withdraw consent. Similarly, a less desirable response to Question 7 would include, the potential participant stating that they would be unsupportive or not accepting of their partner's desire to withdraw consent. In other words, in most cases, the researcher's determination of whether a couple should be included in the study relied more on a consistent pattern of problematic responses to the prescreening interview questions rather than one single less-desirable response.

Based on each potential participant's responses during the pre-screening interview, the researcher determined whether the couple was eligible to participate in the study. Potential participants that completed the pre-study visit and pre-screening interview were excluded from this study if (1) they disclosed that they were uncomfortable participating, would have difficulty conveying a desire to withdraw consent to their partner and/or the researcher, and/or difficulty accepting their partner's desire to withdraw consent from the study; and/or (2) their interview responses suggested a power imbalance in

their relationship with their partner. No couples were excluded from this study based on their responses during the pre-study interview.

The pre-study interview also gave the couples a chance to see the laboratory set up ahead of time, review the consent form verbally with the researcher, and ask any pertinent questions.

Fig. 4 outlines the recruitment and screening process as well as accounts for included and excluded participants in this study.

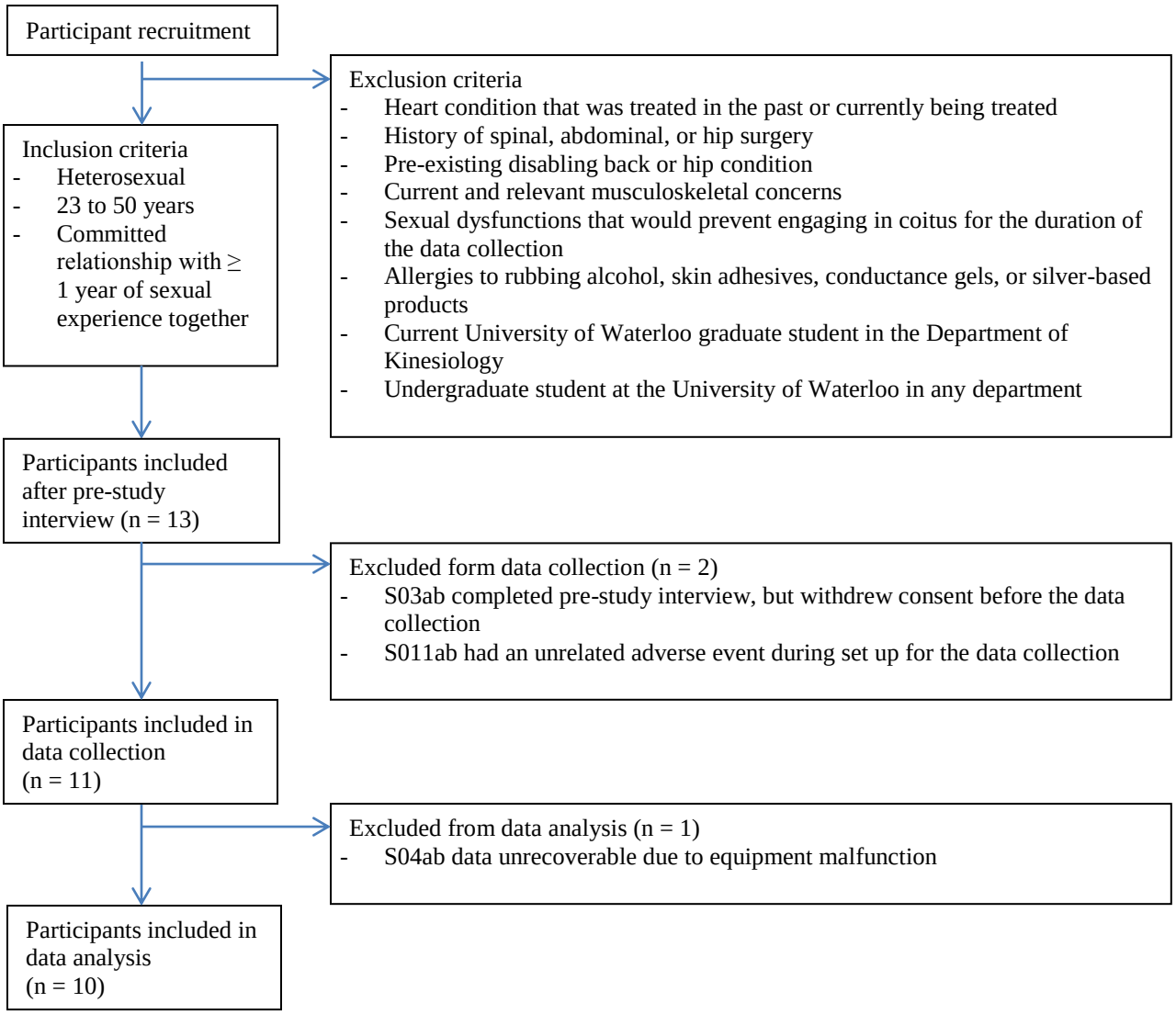


Fig. 4. Summary of recruitment and screening process and included and excluded participants in this study. The final sample size included for data analysis was ten.

3.2 Experimental design

This study was a repeated measured design, where the independent variables, coital position and condition, were varied five (i.e., QUADRUPED1, QUADRUPED2, MISSIONARY1, MISSIONARY2, and SIDELYING) and two (i.e., real and simulated) times, respectively. Recruited participants engaged in coitus on a coil-spring mattress, box spring, and metal frame in five pre-selected positions (presented in random order) for 20 seconds per positions. All coital position trials were performed on the same day. Three-dimensional (3D) lumbar spine and hip kinematic data and electromyography (EMG) signals were continuously collected for the duration of each trial. The kinematic data and EMG signals were collected simultaneously for both participants.

The dependent variables in this study were the 3D lumbar spine (i.e., flexion/extension, lateral flexion, and axial rotation) and hip (i.e., flexion/extension, internal/external rotation, and abduction/adduction) angular displacements and EMG signal amplitudes of selected trunk, hip, and thigh muscles.

3.3 Laboratory preparation

Prior to the couple's arrival on each collection day, some necessary procedures were performed to prepare the laboratory for the data collection. For example, drift in the electronic equipment is an inherent error. To minimize the occurrence of drift over the duration of the data collection, the electronic equipment was turned on to warm up a minimum of one hour prior to the start of the data collection.

3.3.1 Calibration of the optoelectronic motion capture system

Prior to each data collection, eight motion tracking cameras (Vicon MX20+, Vicon Motion Systems, Oxford, UK) were aimed, focused, and calibrated. A five-marker calibration wand (240 millimeters; Vicon Motion Systems, Oxford, UK) that is instrumented with five individual reflective markers (Vicon MX, 12.5 millimeters in diameter, Vicon Motion Systems, Oxford, UK) was placed in the approximate center of the motion capture collection volume. Each of the eight cameras were aimed at, and focused on, the calibration wand to ensure that all reflective markers in the collection volume were visible to the cameras. At this time, any unwanted reflective materials seen by the cameras were covered in the collection volume or 'masked' in the motion capture software.

A dynamic calibration was then performed by waving the calibration wand through the collection volume, which enabled each camera to record the wand position and the motion capture system to define the collection volume and the relative orientation of the cameras. The dynamic calibration was deemed acceptable when the root mean square (RMS) error between the recorded and real locations of the reflective markers was less than 0.20 millimeters for each camera.

Finally, the origin of the collection volume was set by placing the calibration wand on the ground within the defined collection volume and positioning the wand according to the 3D right-handed (Cartesian) coordinate system.

3.4 Instrumentation and experimental protocol

A summary of the experimental protocol is found below in Fig. 5 and described in detail throughout this section.

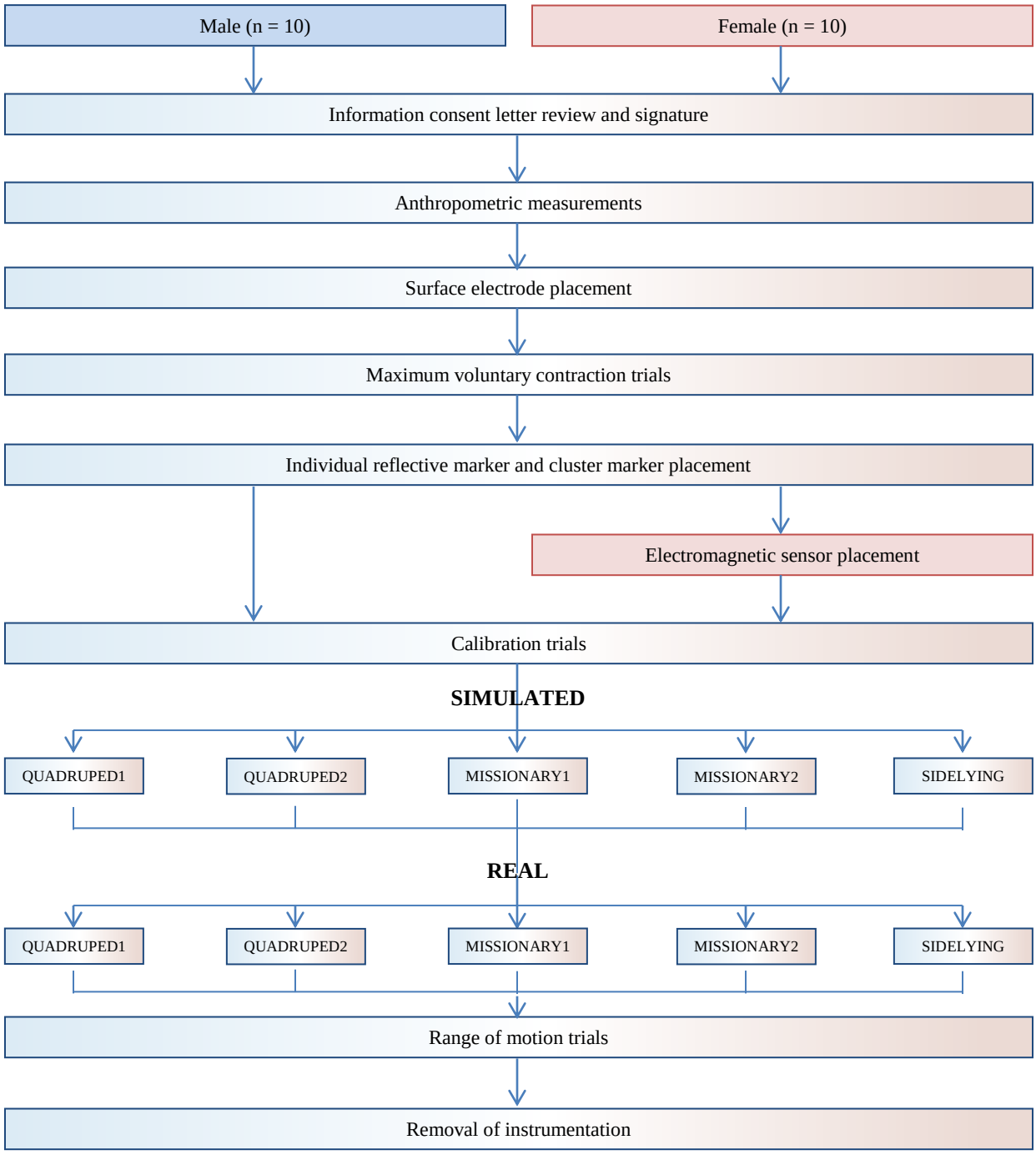


Fig. 5. Summary of the experimental protocol.

If the couple was unable to sign the information consent letter (ICL) during the pre-study interview or requested additional time to review the ICL, it was reviewed again upon their arrival to the laboratory and informed consent was obtained from each participant.

3.4.1 Anthropometric measurements

Each participant's self-reported age was recorded and anthropometric measurements (Table 1) were performed using calipers and a standard weight scale (with height rod). These were used for determining segmental properties. Whenever possible, the same research assistant collected these measurements for consistency.

Table 1. Summary of anthropometric measurements taken from each male and female participant.

Anthropometric Measure	Anatomical Landmarks	Instrumentation
Height	Ground to top of head when standing upright	Standing weight scale with height rod
Weight		Standing weight scale with height rod
Chest depth	Anterior/posterior length of T4 dermatome (at the nipple line)	Calipers
Pelvis width	Right to left greater trochanter	Calipers
Pelvis depth	Right ASIS to right PSIS	Calipers

3.4.2 Electromyography (EMG) signal

3.4.2.1 Electrode placement preparation

EMG signals of each participant were measured unilaterally (right side) from the following six trunk muscles and one hip and thigh muscle: rectus abdominus (RA), external oblique (EO), internal oblique (IO), thoracic erector spinae (UES, longissimus thoracis and iliocostalis lumborum pars thoracis), lumbar erector spinae (LES, longissimus thoracis and iliocostalis lumborum pars lumborum), latissimus dorsi (LD), gluteus maximus (GMax), and biceps femoris (BF), respectively. To measure the EMG signal of these selected muscles with the least electrode-skin interface impedance (Winter 2009), the skin over the muscles where surface electrodes were placed was shaved with a new disposable razor, rubbed with an abrasive skin gel (Nuprep®, Weaver and Company, Cambridge, ON, CAN), and cleaned using rubbing alcohol. Pre-gelled, disposable, monopolar Ag-AgCl disc-shaped surface electrodes (30 millimeter diameter, Ambu® Blue Sensor N, Ballerup, Denmark) were then placed on the skin over each muscle of interest. Two electrodes (30 millimeter interelectrode distance) were placed at each muscle site, so that the difference in potential between the electrodes could be recorded (i.e., a bipolar configuration) (Winter 2009). Non-woven, adhesive fabric (Hypafix™, Smith & Nephew, Mississauga, ON, CAN) and adhesive tape (3M, St. Paul, MN, USA) were used for the fixation of the electrodes and the cables to the skin, respectively. This fixation ensured that the electrodes were properly secured to the skin, movement was not hindered, and cables were not pulling the electrodes.

Electrode placements and orientations on the skin over the selected muscles of the trunk, hip, and thigh were consistent with recommendations from the Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) project and well-established surface EMG electrode placements for the abdominal wall (McGill et al. 1996) – these electrode arrangements have been shown to best represent the differential muscle activity patterns and minimize signal cross-talk between electrode pairs during bending and twisting tasks (Lafortune et al. 1988 cited in McGill 1992). Specific surface EMG electrode

placement locations and orientations for this research project are outlined in Table 2 and illustrated in Fig. 6. Reference electrodes were placed on the right acromion of each participant.

Table 2. Summary of electrode placement locations and orientations for male and female participants.

Signal Channel Name	Muscle (8)	Surface Electrode Placement Description
RA	rectus abdominus	3 cm lateral to the umbilicus in the vertical direction (McGill et al. 1996)
EO	external oblique	Approximately 15 cm lateral to the umbilicus and at the transverse level of the umbilicus (McGill et al. 1996)
IO	internal oblique	Approximately 50 percent on the line between the ASIS and the midline, just superior to the inguinal ligament (Axler & McGill 1997)
LES	lumbar erector spinae (longissimus thoracis and iliocostalis lumborum pars lumborum)	3 cm lateral to the third lumbar vertebra spinous process in the vertical direction (McGill et al. 1996)
UES	thoracic erector spinae (longissimus thoracis and iliocostalis lumborum pars thoracis)	5 cm lateral to the ninth thoracic vertebra spinous process in the vertical direction (McGill 1992)
LD	latissimus dorsi	Lateral to the ninth thoracic vertebra spinous process over the muscle belly (McGill 1992)
GMax	gluteus maximus	Approximately 50 percent on the line between the sacral vertebrae and the greater trochanter in the direction of the line from the PSIS to the middle of the posterior aspect of the thigh (SENIAM [updated 1999])
BF	biceps femoris	Approximately 50 percent on the line between the ischial tuberosity and the lateral epicondyle of the tibia in the direction of the line between the ischial tuberosity and the lateral epicondyle of the tibia (SENIAM [updated 1999])

Note: All electrode placement descriptions are referring to the right side only.

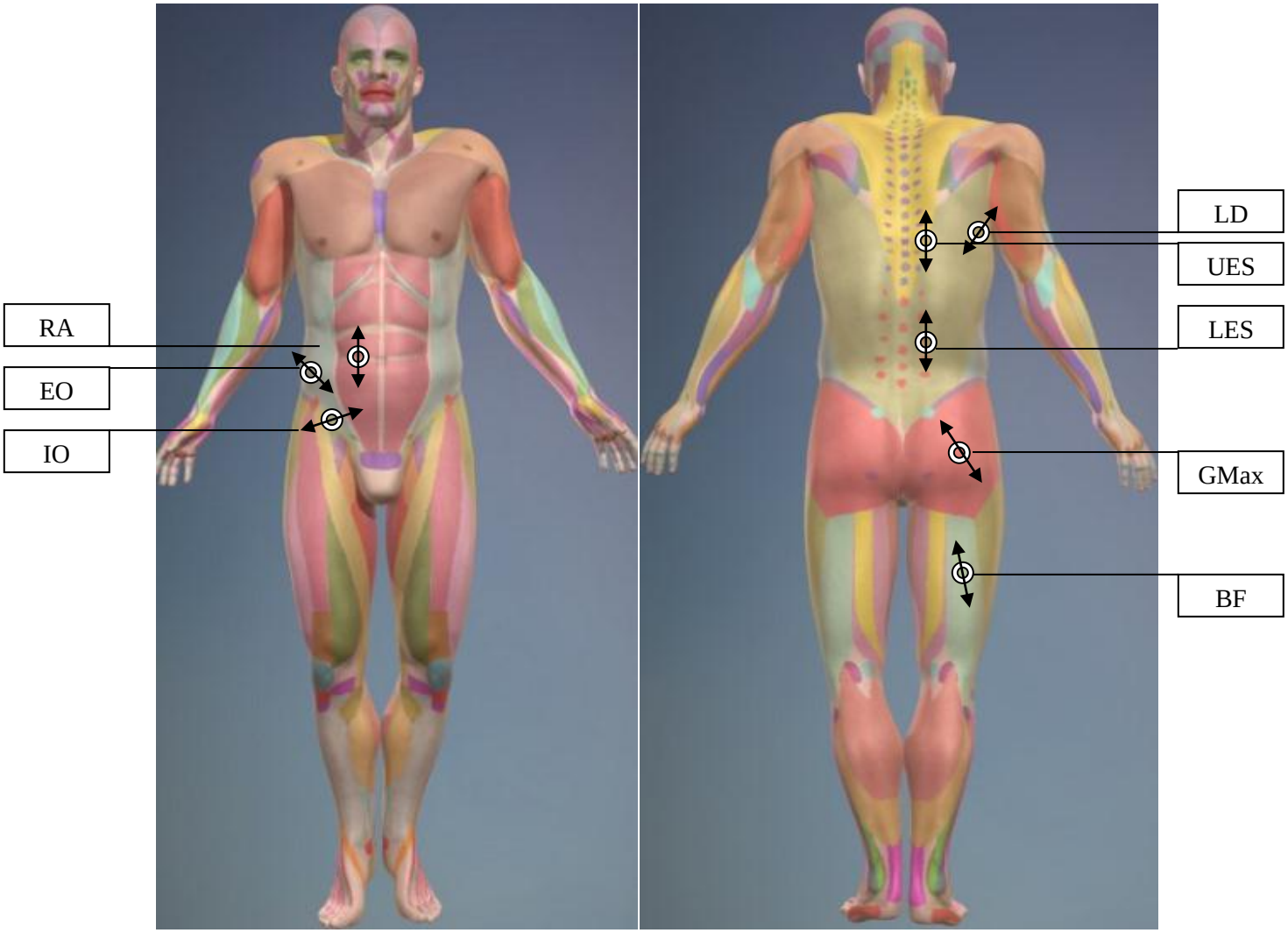


Fig. 6. Illustration of electrode placement locations for male and female participants.
(Primal Pictures Interactive Anatomy 2009). Each open circle represents two surface electrodes and each double-headed arrow represents the orientation of the electrode pair.

3.4.2.2 Maximum voluntary contraction (MVC) trials

Five maximum voluntary contraction (MVC) tasks were performed against manual isometric resistance (consistent with SENIAM [updated 1999] recommendations). The MVC trials were performed with the intention of producing the largest amplitudes of myoelectric activity from the selected trunk, hip, and thigh muscles of each participant to provide a basis for normalization of these EMG signals. MVC trials were repeated three times with a minimum rest period of two minutes between the contractions (De Luca 1997). Two quiet-lying trials (one with the participant supine and one prone) were then performed – the raw EMG signal amplitude data from these trials was used to remove the zero-bias from each EMG signal channel.

The spine extensors (i.e., UES and LES on the right side) were normalized to the maximal EMG activity recorded while the subjects were lying prone on a table with their torso (ASIS and above) cantilevered over the edge of the table (i.e., Biering-Sorenson position). The feet were secured with manual resistance by the researcher. While in this position, subjects started with a slightly-flexed lumbar region and then slowly extended the lumbar spine against a resistance applied on the upper back by the research assistant (McGill et al. 1996).

Maximal abdominal muscle (i.e., RA, EO, and IO on the right side) activation was obtained with the subject in a seated bent-knee 'sit-up' posture with the trunk reclined to approximately 30 degrees with the horizontal and the feet restrained by manual resistance from the researcher. The subject's hands were placed on opposite shoulders while the research assistant provided matched resistance to the shoulders from behind. The instructions for the exertions were to perform a sequence of maximal isometric efforts in trunk flexion, right and left lateral bend, and right and left axial rotation.

GMax (on the right side) was normalized to the maximal EMG activity recorded while the subject was laying prone on a table and lifting their entire right leg against matched resistance provided by the research assistant (SENIAM [updated 1999]).

Maximum activation of BF (on the right side) was obtained by asking the subject to lie prone with their thigh resting on the table and their knee flexed (to less than 90 degrees) with the thigh in slight lateral rotation and the lower leg in slight lateral rotation with respect to the thigh. The research assistant then applied a matched resistance against the right leg, proximal to the ankle in the direction of knee extension as the subject attempted to flex their right knee and extend their right hip (SENIAM [updated 1999]).

Maximal LD (on the right side) activation was obtained by having the subject in a standing posture with their right shoulder abducted, flexed, and horizontally abducted to approximately 45 degrees and their elbow flexed to 90 degrees. As the subject attempted to adduct their shoulder, the research assistant provided matched resistance in the opposite direction.

3.4.3 Kinematics

To quantitatively measure the 3D lumbar spine and hip kinematics, the thorax, pelvis, and right lower leg were considered necessary to monitor. Thorax and pelvis motion were tracked with their respective tracking clusters; however thigh motion was tracked with its adjacent segments (i.e., pelvis and lower leg), since this has been shown to minimize motion artifact (Frost et al. 2012). Since the researcher was monitoring the data collection from the perspective of the virtual collection space on the computer monitors, the head, right upper arm, forearm, hand, thigh, and foot were also monitored to ensure that couples were in the correct positions throughout the data collection.

An optoelectronic system was used to monitor all segments with the exception of the female's thorax – an electromagnetic system was used for this. To improve the accuracy of kinematic data measurements and avoid aliasing where erroneous frequencies that were not present in the original signal would be produced (Winter & Patla 1997), captured kinematic data was oversampled at rates of 30 and 60 hertz (for the electromagnetic and optoelectronic motion capture systems, respectively), which is well over at least twice as high as the highest frequency present in human movement signal (Winter & Patla 1997); thus, in accordance with the Sampling Theorem. The optoelectronic and electromagnetic motion capture systems were synchronized using an external trigger box.

3.4.3.1 Optoelectronic motion capture system

3D kinematic data of all segments of the male and female participants (with the exception of the female's thorax) was monitored using eight motion tracking infrared cameras (Vicon MX20+, Vicon Motion Systems, Oxford, UK). This Vicon motion capture system has a reported resolution of two megapixels (1600 x 1280 pixels) (Vicon Motion Systems).

The cameras monitored the location of 20 individual (i.e., calibration markers) spherical reflective markers (Vicon MX, 12.5 millimeters in diameter, Vicon Motion Systems, Oxford, UK) and nine rigid marker clusters (i.e., tracking clusters) each instrumented with three to five non-colinear individual spherical reflective markers. Following anthropometric measurements, the markers and clusters were secured to each male and female participant's skin with adhesive tape over anatomical landmarks outlines in Table 3 and illustrated in Fig. 7.

Table 3. Summary of marker placement locations for male and female participants.

Marker Name	Anatomical Landmark	Marker Placement Description
rEAR*/lEAR*	Right and left earlobe	
rAC*/lAC*	Right and left acromial process	Cranio-lateral aspect
rIC*/lIC*	Right and left iliac crest	Most lateral and caudal on the ilium
rGT*/lGT*	Right and left greater trochanter	
rMFE*/rLFE*	Right medial and lateral femoral epicondyle	Most caudal point
rMM*/rLM*	Right medial and lateral malleolus	
rMT1*/rMT5*	Right first and fifth metatarsal	
rME*/rLE*	Right medial and lateral epicondyle	
rMWr*/rLWr*	Right head of ulna / right styloid process of radius	
rMC1*/rMC5*	Right first and fifth metacarpal	
HEAD+	Skull	Lateral aspect (right side) above the right ear
rARM+	Right upper arm	Latero-proximal
rFA+	Right forearm	Medial
rHAN+	Over the metacarpal bones of the right hand	
T12+	Spinous process of the twelfth thoracic vertebra	N/A for female participants
S1+	Sacrum	For female participants, lateral aspect of the pelvis (right side)
rTHIGH+	Shaft of the right femur	Latero-distal (Leardini et al. 1999)
rSHANK+	Right lower leg	Latero-distal
rFOOT+	Over the metatarsal bones of the right foot	Latero-distal

* represents individual calibration markers and + represents tracking clusters.

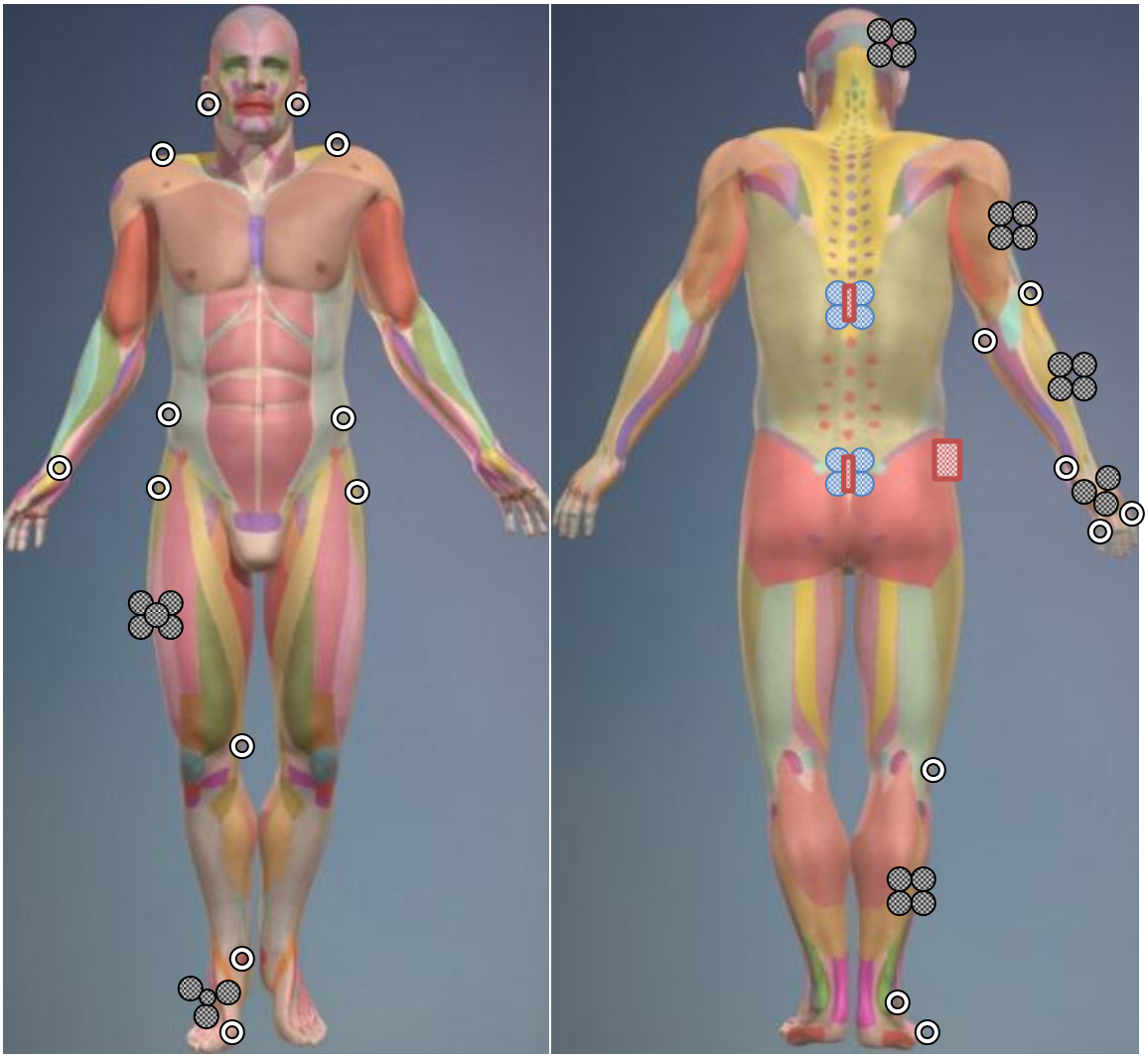


Fig. 7. Illustration of reflective marker and electromagnetic sensor placement locations for male and female participants.
(Primal Pictures Interactive Anatomy 2009). Open circles – calibration markers, filled black/white circles – tracking clusters used for males and females during the collection, filled blue circles – tracking clusters used for males only, filled red rectangles – sensors used for females only.

Once both male and female participants were instrumented with the calibration markers and tracking clusters (indicated in Table 3), a static calibration was performed. Following the static calibration of the subject, the calibration markers were removed. The researcher ensured that all markers were visible to at least three cameras at all times throughout the data collection.

3.4.3.2 Electromagnetic motion capture system

An alternative to using the aforementioned optoelectronic motion capture system to monitor female participants' 3D lumbar spine kinematic data was necessary because in most of the sexual positions chosen for this study; rigid marker clusters on the twelfth thoracic spinous process and the sacrum of the

female participant would have been occluded from the cameras. Instead, the female participants' 3D lumbar spine data was monitored using an electromagnetic motion capture system (3SPACE Isotrak®, Polhemus, Vermont, USA).

The electromagnetic motion capture system is a camera-less 3D human motion measurement system that uses a transmitter (i.e., 'source'), which generates a varying electromagnetic field, and a receiver (i.e., 'sensor'), which senses the electromagnetic field; the position and orientation of the receiver relative to the transmitter is recorded (McGill et al. 1997). This system's known methodological considerations include restricting metallic objects in the electromagnetic field due to a possible effect on the accuracy of the system (McGill et al. 1997). Despite the use of a coil-spring mattress in this study, pilot testing did not reveal an issue with the accuracy of the 3SPACE device. This is assumed to be due to the present metal being outside of the sensitive zone between the transmitter and the sensor.

To measure the female lumbar spine kinematics, the 'source' was secured to the lateral aspect (right side) of the pelvis with a sacrum belt, one sensor was placed on the twelfth thoracic spinous process and secured underneath fabric hook-and-loop-fastener elastic straps and the other sensor was embedded in the sacrum belt over the sacrum. The second sensor was placed there as a 'dummy' sensor, so that the electromagnetic motion capture system would operate optimally.

When the female was in the supine position during MISSIONARY1 and MISSIONARY 2 (see below for description of coital positions) the sensors were pressed between the mattress and the female subject. Pilot testing and feedback from female study participants confirmed that lying supine on the sensors did not add discomfort to how they were already feeling from the fabric hook-and-fastener elastic straps and tracking clusters firmly secured to their skin nor was there additional noise introduced in the outputs from the electromagnetic motion capture system. Given the small dimensions of the sensors (Fig. 8), care that was taken to properly secure the sensors to the female participant's skin, and the soft mattress used to conduct this study, potential participant discomfort, compression of sensors, and impact on measures was prevented as much as possible and resulted in outputs of comparable quality to the other coital positions studied.

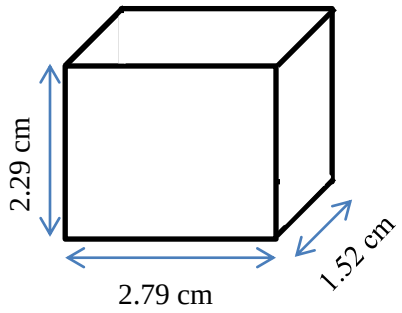


Fig. 8. Physical characteristics of the receiver (drawn to scale).

3.4.4 Coital positions

Participants were instructed to move as naturally as possible as they engaged in coitus in five pre-selected positions and simulated and real conditions (see below). The order that participants performed the positions in was randomized. Participants were asked to engage in each sexual position for 20 seconds in a simulated condition (i.e., clothed and mimicking coital movements in each position) followed by the

same sexual positions for 20 seconds in a real condition. The cues given for each position (outlined below) were identical for simulated and real conditions. One penetration cycle was defined by a kinematic threshold indicator – maximum hip flexion achieved by the male participant.

Trial duration of 20 seconds was deemed appropriate based on the literature on ejaculation latency time (ELT) in men with normal sexual function. The average ELT of these men during sexual intercourse ranged from 5.6 (SD ± 0.9) minutes (Rowland et al. 2000) to 8.1 (SD ± 7.1) minutes (Waldinger et al. 2005) and 9.15 (SD ± 7.17) minutes (Patrick et al. 2005). The reported median and range of ELT during intercourse in men with normal sexual function ranged from 6.5 minutes (18 to 30 years of age [Waldinger et al. 2005]) to 7.3 minutes (Patrick et al. 2005) and 8.25 and 1.32 to 18.31 minutes (Vanden Broucke et al. 2007), respectively. Even with sufficiently lower trial times than the shortest reported ELT during intercourse, participants were encouraged to take as many breaks as needed to prevent ejaculation from occurring during the data collection.

Five sexual positions (shown in Fig. 9, Fig. 10, and Fig. 11) were chosen for this study based on the findings of previous literature and a biomechanical rationale. Since the main objective of this study was to describe coital movement, cues for coital posture and movement were intentionally minimal, yet sufficient to ensure that the same coital positions were being performed across couples. In addition to verbal cueing provided to participants before the data collection began (outlined below for each coital position), illustrations of each position (Fig. 9a, Fig. 9b, Fig. 10a, Fig. 10b, and Fig. 11a) were affixed to the laboratory wall in their randomized order to remind participants of the order in which to perform the coital positions and variations throughout the data collection. Participants were reminded to use the illustrations only as a guide to order, but to rely on the verbal cues from the researcher (outlined below) to conduct each coital position.

QUADRUPED was included in this biomechanical analysis because the female participant's position is comparable to that of a 'cat/camel' motion starting position – a position reported to strain the lumbar spine the least while conducting lumbar spine active range of motion (aROM) (McGill 2007) – and the male participant's position allows for a great range of hip motion, which may reduce the range of motion (ROM) of the lumbar spine. Based on feedback from pilot participants, two variations of QUADRUPED were included in this study: QUADRUPED1 where the female is supporting her upper body with her elbows and QUADRUPED2 where the female is supporting her upper body with her hands. For both simulated and real conditions, female participants were cued to have their knees, shanks, and elbows or hands (depending on the variation of QUADRUPED being performed) remain in contact with the mattress and males were cued to have their knees and shanks in contact with the mattress.

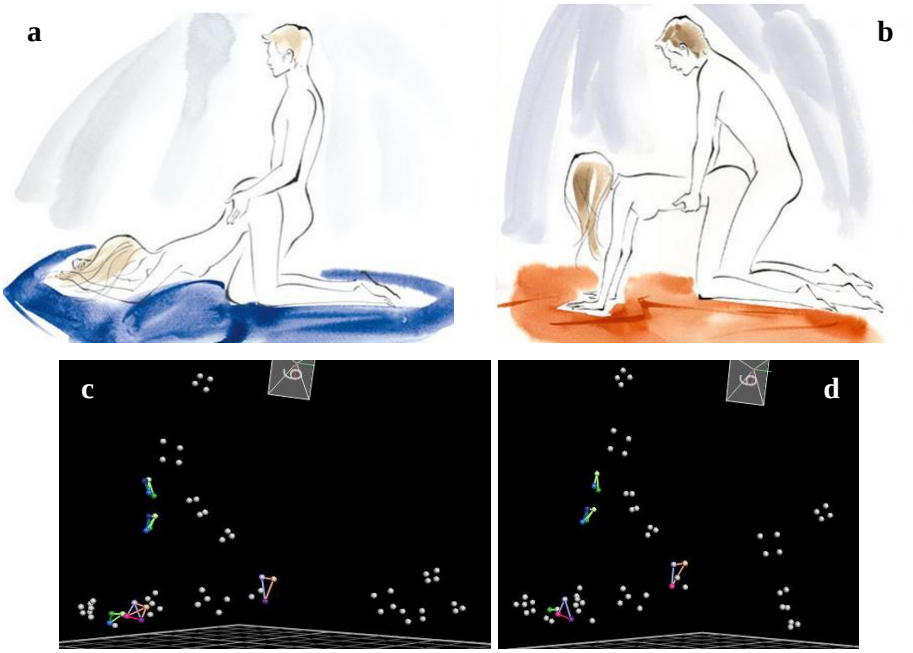


Fig. 9. QUADRUPED – rear-entry, female quadruped, male kneeling behind.
The first variation of QUADRUPED, where the female is supporting her upper body with her elbows is illustrated (Men's Health[b]) here (a) and shown as the researcher would see it during data collection in the optoelectronic motion capture system software (c). The second variation of QUADRUPED, where the female is supporting her upper body with her hands is also illustrated (Men's Health[a]) here (b) and shown in the optoelectronic motion capture system software (d). For both variations of QUADRUPED, the male's posture does not change. He remains kneeling behind the female. Note that the illustrations in (a) and (b) do not necessarily represent male or female spine and hip posture found in this study – the illustrations are an artistic interpretation of the variations of QUADRUPED that provide the reader with a visual representation of the verbal description given in this document.

MISSIONARY (i.e., front-entry, female supine, male prone on top) has been reported as the most painful coital positions for males and least painful coital position for females, whereas SIDELYING (i.e., rear-entry, female side-lying, male side-lying behind) has been reported as the second least painful coital position for both males and females (Maigne & Chatellier 2001; Sjögren & Fugl-Meyer 1981). Based on a basic biomechanical rationale, SIDELYING has been recommended as a coital position that may place the lumbar spine under the least amount of strain (Osborne & Maruta 1980; White & Panjabi 1990). Based on feedback from pilot participants, two variations of MISSIONARY were included in this study: MISSIONARY1 where the male is supporting his upper body with his hands and the female is not flexing her hips or knees and MISSIONARY2 where the male is supporting his upper body with his elbows and the female is flexing her hips and knees. For both simulated and real conditions of MISSIONARY, female participants were cued to lay supine with their hips and knees either flexed or extended (depending on the variation of MISSIONARY being performed) with feet remaining in contact with the mattress and males were cued to have their knees and shanks in contact with the mattress as well as their elbows or hands (depending on the variation of MISSIONARY being performed). For both simulated and real conditions of SIDELYING, both male and female participants were cued to lie on their left sides.

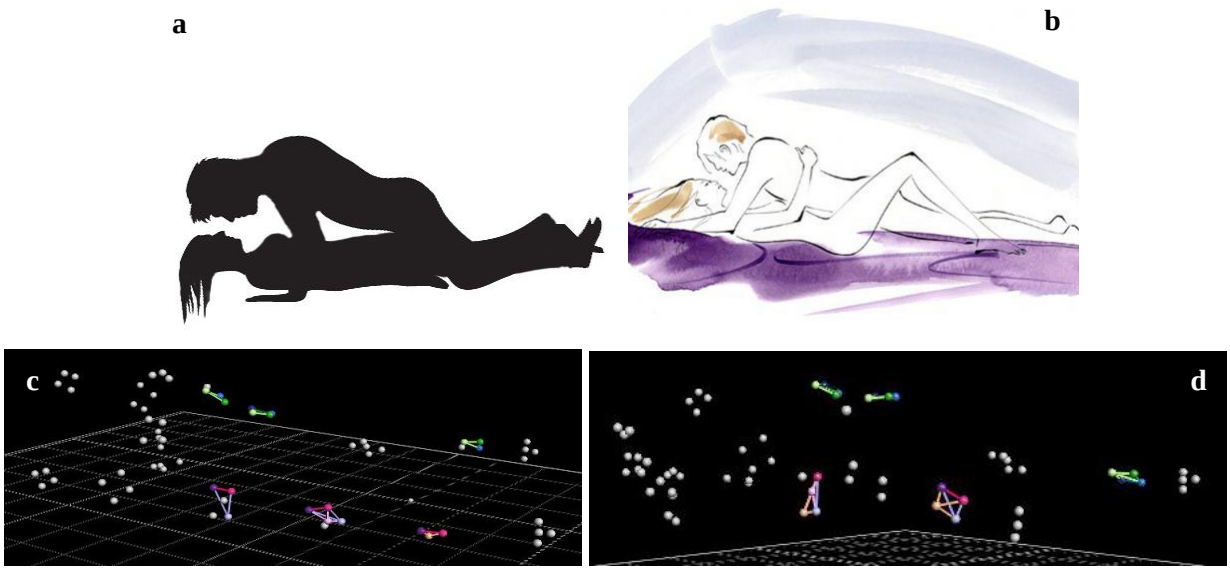


Fig. 10. MISSIONARY – front-entry, female supine, male prone on top.
The first variation of MISSIONARY, where the male is supporting his upper body with his hands and the female does not have her hips or knees flexed is illustrated (Chelsey) here (a) and shown in the optoelectronic motion capture system software (c). The second variation of MISSIONARY, where the male is supporting his upper body with his elbows and the female has her hips and knees flexed is also illustrated (Men's Health[c]) here (b) and shown in the optoelectronic motion capture system software (d). Note that the illustrations in (a) and (b) do not necessarily represent male or female spine and hip posture found in this study – the illustrations are an artistic interpretation of the variations of MISSIONARY that provide the reader with a visual representation of the verbal description given in this document.

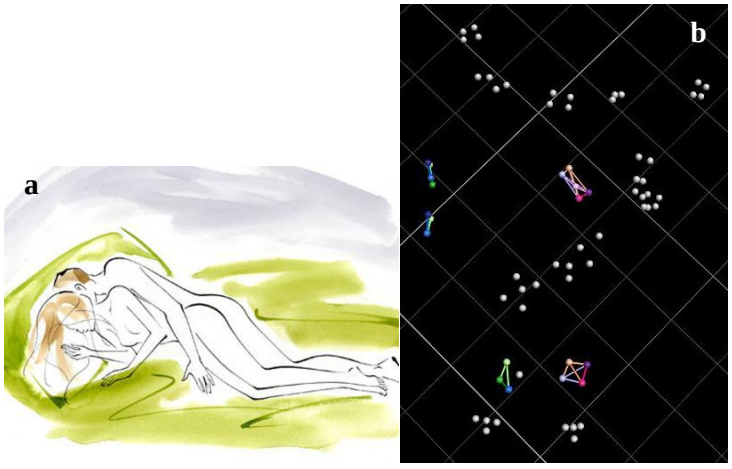


Fig. 11. SIDELYING – rear-entry, female side-lying, male side-lying behind.
SIDELYING is illustrated (Men's Health[d]) here (a) and shown in the optoelectronic motion capture system software (b). Note that the illustrations in (a) and (b) do not necessarily represent male or female spine and hip posture found in this study – the illustrations are an artistic interpretation of the variations of SIDELYING that provide the reader with a visual representation of the verbal description given in this document.

3.4.5 Active ROM (aROM)

Active range of motion (aROM) of the lumbar spine (i.e., flexion/extension, lateral flexion, and axial rotation) and hips (i.e., flexion/extension, abduction/adduction, and internal/external rotation) was measured using the optoelectronic (i.e., male lumbar spine and hip aROM and female hip aROM) and electromagnetic (i.e., female lumbar spine aROM) motion capture systems. Hip aROM was only measured on the right hip for both males and females.

To measure all ranges of lumbar spine motion, the subject was asked to stand in a neutral posture at rest and bend forward, extend back, side-bend (to the left and right), and twist (to the left and right) at the waist as far as they could.

To measure all ranges of hip motion, the subject was asked to stand in a neutral posture at rest and flex, extend, abduct, and rotate their hip as much as possible.

3.5 Data Processing

3.5.1 Electromyography

To improve the accuracy of EMG amplitude measurements, the raw EMG signal was oversampled at a rate of 2160 hertz, which is over the recommended sampling rate (2000 Hz) of four times the highest frequency of surface EMG signal (500 Hz) (Durkin & Callaghan 2005; Winter & Patla 1997).

Raw EMG was filtered using a second-order, band-pass filter with cut-off frequencies of 30 to 500 Hz to preserve as much of the biological signal and filter out as much electrocardiographic signal (Drake & Callaghan 2006) and noise as possible.

The filtered EMG data was then amplified with two eight-channel differential amplifiers (common-mode rejection ratio of 115 d dβ at 60 Hz; input impedance 10 GΩ; Model AMT-8, Bortec Biomedical, Calgary, AB, CAN) and set to the same amplification setting (gain = 1000). The differential amplifier specifications exceeded recommendations (i.e., common-mode rejection ratio greater than 80 dβ; input impedance greater than 100MΩ) when measuring surface EMG (De Luca 1997). The EMG signals were then analog-to-digital (A/D) converted (Vicon MX 64-channel A/D interface unit) using a 16-bit converter (Vicon MX 20 MX control box) with a ± 2.5 V range. Soft gains were individually set for each channel to fill this input range without clipping the signal. The digitized signal was collected on a personal computer (Vicon Antec® Intel® Core™ 2 Duo PC) using Vicon Nexus 1.7 software.

3.5.2 Kinematics

All raw kinematic data captured with the optoelectronic system was collected with Vicon 1.7 software (Vicon Motion Systems, Oxford, UK). This data was stored on a password-protected central processing unit and imported to Visual 3D (Version 4; C-Motion Inc., Rockville, MD, USA) for filtering and joint angle calculations (see below for higher processing of kinematic data). Regardless of the kinematic data collection instrumentation (i.e., optoelectronic or electromagnetic motion capture systems), the same processing methods described below were used.

Interference from movement artifacts or high frequency noise in the transducer systems may have been present in the raw kinematic data that was collected. All undesired harmonics that were not part of the human movement being sampled were severely attenuated by employing a digital filter. Since the signal power of human movement is typically contained below six hertz (Winter & Patla 1997), all raw kinematic data was filtered using a second-order, low-pass Butterworth filter with an upper cutoff frequency of six hertz.

3.5.3 Higher processing

3.5.3.1 Electromyography

Higher processing of the EMG signal data was performed using a custom computer program in MATLAB software (Version r2009B; The MathWorks Inc., Natick, Massachusetts, USA). The direct current (DC) bias was removed from all trials by subtracting the zero bias calculated from the EMG signal amplitudes in the quiet-lying trials (supine and prone).

The filtered EMG signals were then full-wave rectified (FWR) to generate the absolute value of the EMG (Winter 2009) and low-pass filtered using a second-order, low-pass Butterworth filter (single-passed to introduce a phase lag, which represents electromechanical delay between the onset of the motor unit action potential and the resultant muscle tension) with a cut-off frequency of 2.5 Hz to produce a linear envelope. The linear envelope closely resembled the muscle twitch tension curves of the trunk musculature (Winter 2009) by selecting a 2.5 Hz cut-off frequency that matched the 2.5 Hz twitch response of the trunk musculature (Brereton & McGill 1998).

The EMG signals were then normalized to the maximum EMG signal amplitudes achieved at each muscle site during the MVCs and expressed as a percentage of these maximums. Finally, the normalized EMG signals were down-sampled to 30 Hz to enable the synchronization of the kinematic and EMG data. The down-sampled data was only used for analysis when the time history of kinematic and EMG data needed to remain synchronized.

The normalized EMG signals for each muscle site were used to calculate the peak EMG values and the amplitude probability distribution function (APDF) per position for each. APDF was calculated to gain insight into the distribution of the different levels of muscle contraction achieved while engaging in coitus in each of the five positions, since muscle activity was variable over time. Specifically, the amplitude probability at a certain level of contraction is the probability of the myoelectric activity being lower than or equal to that contraction level during coitus and the APDF determines the range of contraction levels achieved (i.e., the maximum, minimum, and median contraction levels) (Hagberg 1979).

3.5.3.2 Kinematics

Once the kinematic data had been filtered in Visual 3D, this software was be used to determine 3D angular displacement of the lumbar spine and hips. First, models of each segment (i.e., torso, pelvis, and right thigh) were created using the anthropometric measurements taken of each subject and the position of the motion capture system instrumentation (i.e., calibration markers and tracking clusters) during the calibration and data collection trials. Visual 3D estimates joint centers, constructs local coordinate systems, determines angular displacements of the joint centers, and calculates Euler angles for rotations of

the right thigh relative to the pelvis, the pelvis relative to the lumbar spine, and the lumbar spine relative to the GCS and intersegmental angles. Visual 3D calculates the rotations of the thigh relative to the pelvis, the pelvis relative to the lumbar spine, and the lumbar spine relative to the GCS by applying an appropriate direction cosine matrix of Euler angles to the rotation matrices, specifically the X-Y-Z rotation sequence is used. The following direction cosine matrix of Euler angles was used to derive relationships that allow for solving Euler angles phi (φ), psi (ψ), and theta (θ) for the rotations of the thigh relative to the pelvis, the pelvis relative to the lumbar spine, and the lumbar spine relative to the GCS:

$$\underline{\underline{T}}(\underline{\theta}) = \begin{bmatrix} \cos\theta \cdot \cos\Psi & \cos\phi \cdot \sin\Psi + \sin\phi \cdot \sin\theta \cdot \cos\Psi & \sin\phi \cdot \sin\Psi - \cos\phi \cdot \sin\theta \cdot \cos\Psi \\ -\cos\theta \cdot \sin\Psi & \cos\phi \cdot \cos\Psi - \sin\phi \cdot \sin\theta \cdot \sin\Psi & \sin\phi \cdot \cos\Psi + \cos\phi \cdot \sin\theta \cdot \sin\Psi \\ \sin\theta & -\sin\phi \cdot \cos\theta & \cos\phi \cdot \cos\theta \end{bmatrix}$$

Eq. 1. Direction Cosine Matrix from Euler angles (Stationary Frame to Rotated Frame) – Pitch-Yaw-Roll sequence (i, j, k), (X, Y, Z)

Once the Euler angles were calculated, the data was imported into a custom computer program designed using MATLAB software. Due to a small amount of slippage of the sacrum belt on both male and female participants, a bias was introduced. It was assumed that the slippage occurred during the first simulated trial performed, so the bias calculated in the first 10 frames of active range of motion trial conducted at the end of the data collection (when the participant was just quiet-standing) was subtracted from all trials to account for this error. The intersegmental angles were used to calculate the average minimum (Fig. 12) and maximum (Fig. 12) 3D lumbar spine and hip range of motion (expressed as a percentage of each participant's full ROM) values, as well as the average amplitude difference between the maximum and minimum value in a penetration cycle (Fig. 12) and the amplitude probability distribution function (APDF) per position for each participant.

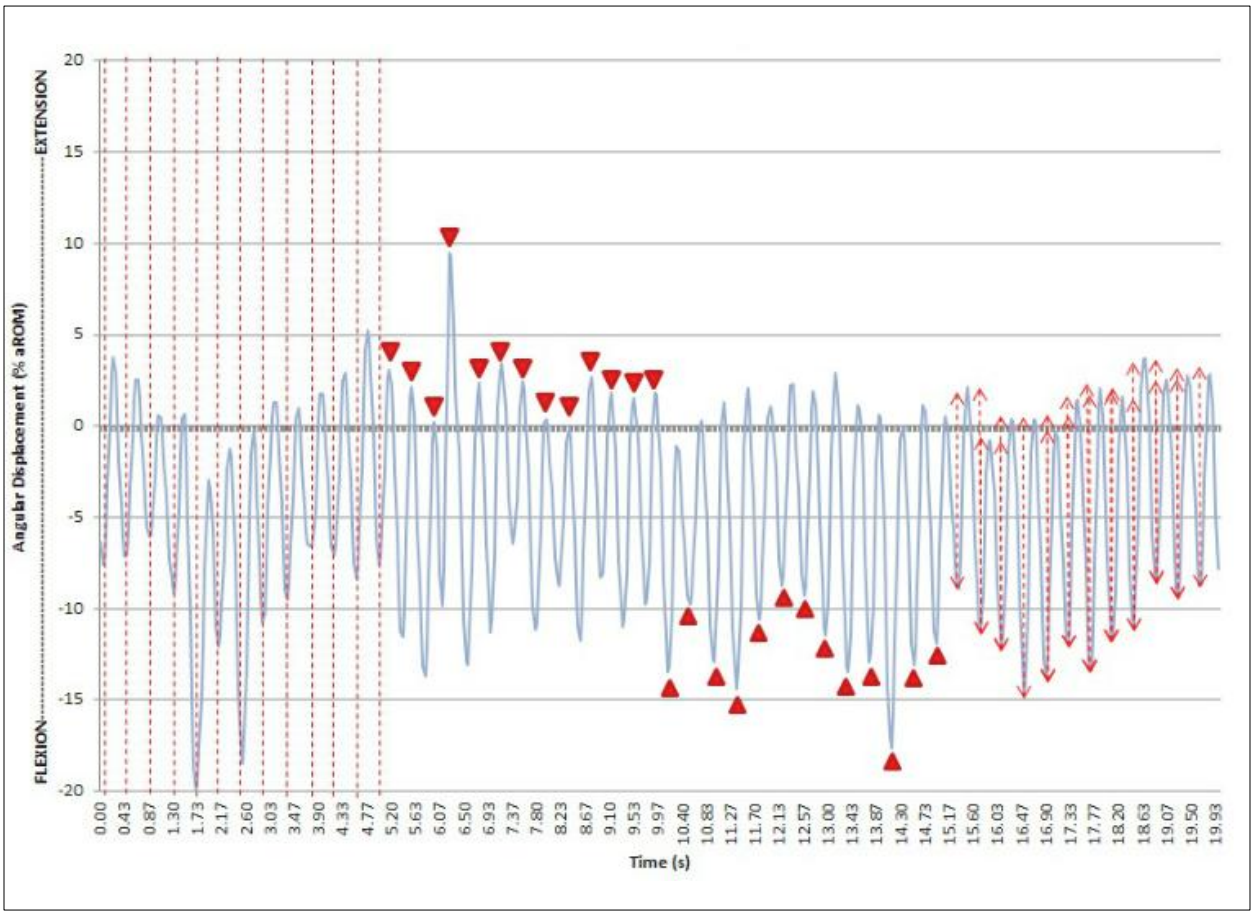


Fig. 12. Illustration of penetration cycle identification and average maximum, minimum, and amplitude difference calculation.
Using sample male hip kinematic data (solid blue line) from the sagittal plane of motion, the identification of penetration cycles (red, dotted lines within the first five seconds), maximums (red, upside-down triangles within the second five seconds), and minimums (red triangles within the third five seconds), and amplitude differences within penetration cycles (red, dashed-lined, double-headed arrows within the last 5 seconds) are indicated. Average maximum, minimum, and amplitude difference values for any trial were calculated by taking an average of all of the maximums, minimums, and amplitude differences identified across all penetration cycles. Averages were used because all aforementioned outcome variables fluctuated throughout a trial (as shown in the sample data presented here).

Although APDF is traditionally used for EMG signal amplitude data, it was also calculated using kinematic data to gain insight into the distribution of the varying levels of active range of motion achieved while engaging in coitus in each of the five positions, since the kinematic data was cyclic in nature, but variable over time. Specifically, the amplitude probability at a certain level of flexion/extension (expressed as a percentage of the participant's full ROM) is the probability of the range of flexion/extension motion being lower than or equal to that level of flexion/extension during coitus and the APDF determined the range of lumbar spine and hip active range of motion achieved (i.e., the maximum, minimum, and median active range of motion levels).

The entire measurement chain and data processing methods described above are summarized in Fig. 13.

3.6 Data analysis

IBM® SPSS ® Statistical software (Version 19, IBM Corporation, Somers, New York, USA) was used for statistical analysis of the data collected. In this study, the independent variables were coital position and condition (i.e., simulated and real) and the dependent variables were the 3D lumbar spine (i.e., flexion/extension, lateral flexion, and axial rotation) and hip (i.e., flexion/extension, internal/external rotation, and abduction/adduction) angular displacements and EMG signal amplitudes of selected trunk, hip, and thigh muscles.

3.6.1 Descriptive statistics

The median, mean, and standard deviation were calculated for all kinematic and EMG outcome variables described above. The median was included to indicate the direction the data was deviating from a normal distribution (i.e., direction of skewness).

3.6.2 Inferential statistics

Regardless of the descriptive nature of this study, hypotheses were formed regarding expected observations. Since males and females assumed entirely different postures within each coital position, they were considered separate groups in the following data analysis to test each hypothesis.

To determine if each coital position had distinct spine and hip kinematic profiles, with the exception of the two variations of MISSIONARY for the males, as well as distinct muscle activation profiles for males, separate univariate general linear models (GLM) (factor: coital position = five levels, α=0.05) followed by Tukey's honestly significant difference (HSD) post hoc analysis was used on each outcome variable described above to examine any main effects of coital position on spine and hip kinematics and muscle activation patterns.

To determine if simulated coitus was representative of real coitus across all spine and hip kinematic variables and muscle activation outcome variables of the trunk musculature, paired-sample t-tests (α=0.05) were performed on all outcome variables described above and their respective simulated values.

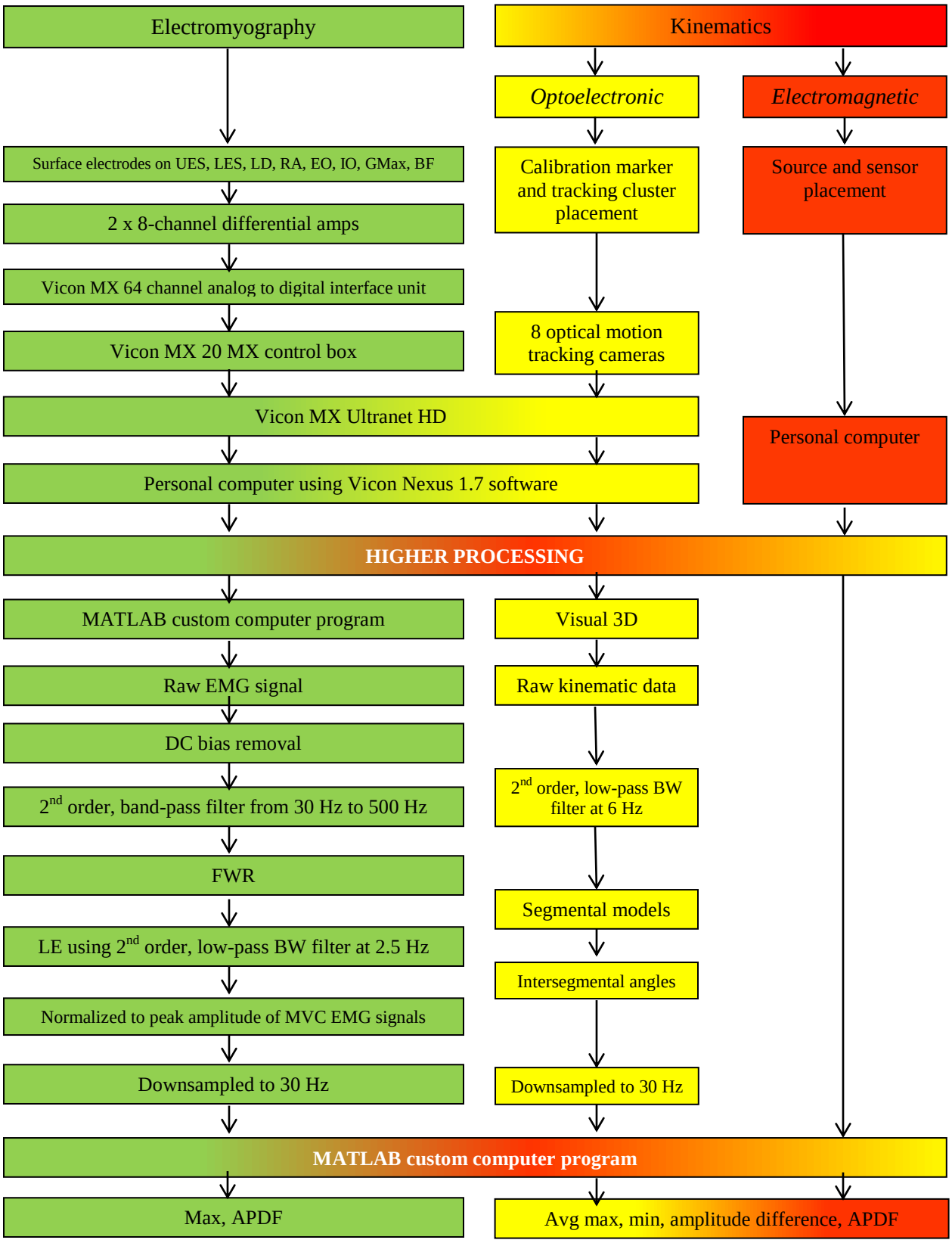


Fig. 13. Summary of measurement chain and data processing methods.

Chapter 4

Results

4.1 Coital position comparison

As a reference for this section and those to follow, Table 4 outlines each coital position with each sex's corresponding posture and abbreviation.

Table 4. A description of each sex's posture during each coital position.

Coital Position	*Male*		*Female*	
	Posture	Abbreviation	Posture	Abbreviation
QUADRUPED1	Kneeling behind	mQUAD1	Quadruped, with elbow support	fQUAD1
QUADRUPED2	Kneeling behind	mQUAD2	Quadruped, with hand support	fQUAD2
MISSIONARY1	Prone on top, with hand support	mMISS1	Supine, with no hip or knee flexion	fMISS1
MISSIONARY2	Prone on top, with elbow support	mMISS2	Supine, with hip and knee flexion	fMISS2
SIDELYING	Side-lying behind	mSIDE	Side-lying	fSIDE

The main objective of this study was to describe and compare male and female spine and hip kinematics and muscle activation patterns during common coital positions.

4.1.1 Kinematics

Upon visual inspection of the male and female kinematic data for all coital positions, it was found that the majority of the kinematic signal was in the sagittal plane (i.e., flexion/extension). To illustrate this, a typical trial (i.e., Subject 5a – mMISS2) is presented in Fig. 14. For this reason, only findings pertaining to the sagittal plane of motion are discussed below. The sign convention for flexion and extension is negative and positive, respectively.

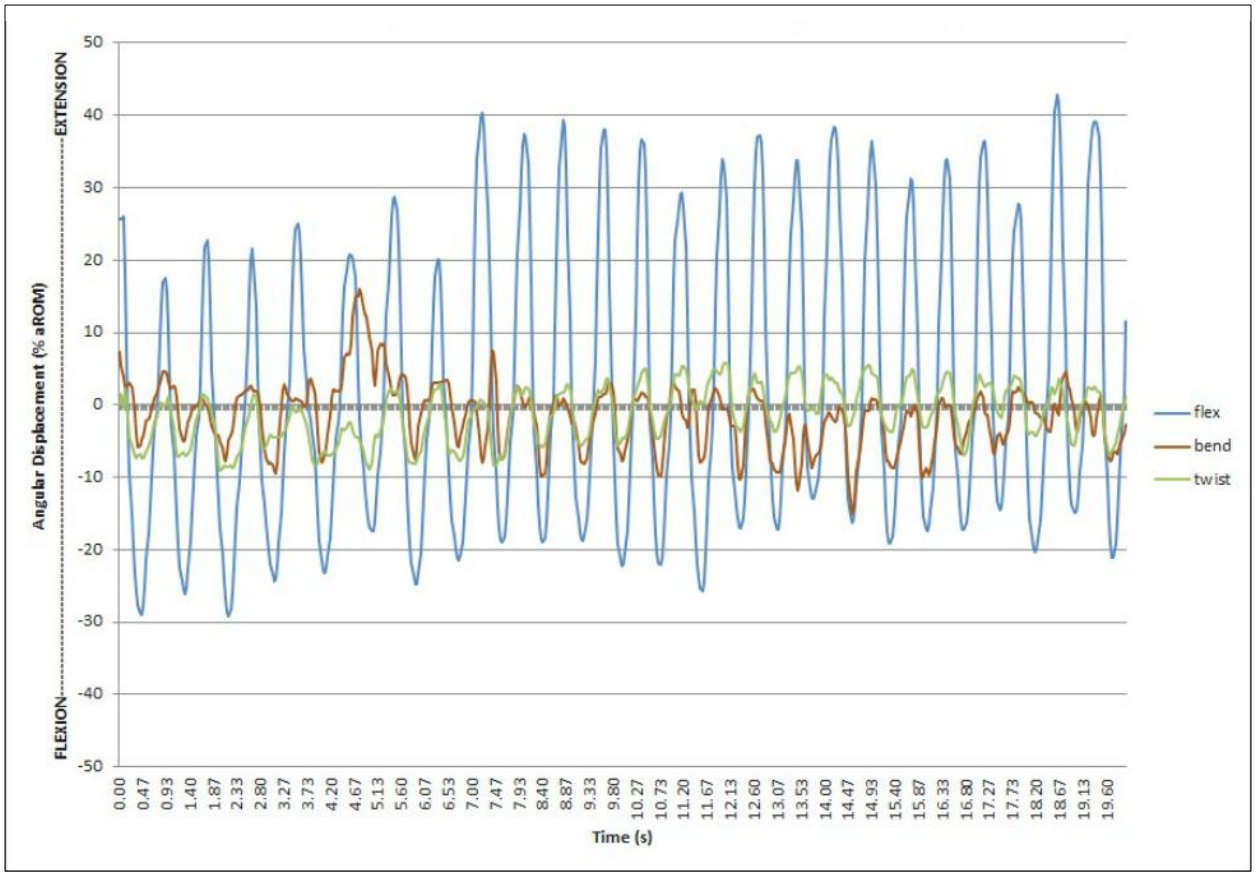


Fig. 14. Presentation of lumbar spine angular displacement (% aROM) in a typical trial of mMISS2 from Subject 5a.

Note that the majority of the kinematic signal was in the sagittal plane of motion (i.e., flex) and that excursion of this signal was approximately 60 percent of lumbar spine active range of motion as opposed to approximately five percent for 'bend' and 'twist'. The movement pattern fluctuated over different ranges of spine motion across 24 penetration cycles.

4.1.1.1 Male

With respect to average speed of penetration cycles, both variations of QUADRUPED, QUADRUPED1 (1.80 ± .72 cycles/s) and QUADRUPED2 (1.81 ± .72 cycles/s) had the fastest speeds, followed by SIDELYING (1.50 ± .60 cycles/s), and both variations of MISSIONARY, MISSIONARY1 (1.37 ± .68 cycles/s) and MISSIONARY2 (1.33 ± .49 cycles/s). Significant differences were found (F=9.271, p<.001) between QUADRUPED1 and MISSIONARY1 (p=.003), MISSIONARY2 (p=.001), and SIDELYING (p=.043). QUADRUPED2 was also found to be significantly different from MISSIONARY1 (p=.002), MISSIONARY2 (p<.001), and SIDELYING (p=.034).

4.1.1.1.1 Lumbar Spine

A summary of male spine kinematic results discussed below can be found in Table 7, Table 8, Table 9, Table 10, and Table 11 within Appendix B.

Male lumbar spine movement varied depending on the coital position (Fig. 15); however, across all positions, the majority of the range of motion used was in flexion. The average maximum percentage of flexion aROM reached in a penetration cycle was highest for mSIDE (-60.97 ± 15.60 % aROM) and mMISS2 (-44.88 ± 19.78 % aROM). The other three positions, mMISS1 (-23.87 ± 23.72 % aROM), mQUAD2 (-22.46 ± 15.99 % aROM), and mQUAD1 (-8.61 ± 31.33 % aROM), reached a significantly lesser percentage of flexion aROM across all penetration cycles. Significant differences were found (F=9.413, p<.001) between mSIDE and mQUAD1 (p<.001), mQUAD2 (p=.001), and mMISS1 (p=.002). mMISS2 was also significantly different from mQUAD1 (p=.002). The average maximum percentage of [extension] lumbar spine aROM reached in a penetration cycle was greatest during mQUAD1 (15.04 ± 34.96 % aROM) and mMISS1 (13.98 ± 42.83 % aROM) – only these two positions achieved extension – and least during mSIDE (-35.24 ± 21.35 % aROM). Both mQUAD1 (p=.007) and mMISS1 (p=.008) were significantly greater than mSIDE (F=4.848, p=.005).

The average amplitude difference between maximum and minimum percentages of lumbar spine aROM within a penetration cycle, across all cycles, (Fig. 15) was highest for both variations of PRONE, mMISS2 (44.10 ± 17.55 % aROM) and mMISS1 (37.86 ± 35.43 % aROM), followed by mSIDE (25.76 ± 14.66), and both variations of mQUAD, mQUAD1 (23.68 ± 19.54) and mQUAD2 (13.26 ± 11.52 % aROM). Only mQUAD2 was significantly different (F=3.111, p=.032) from mMISS2 (p=.011).

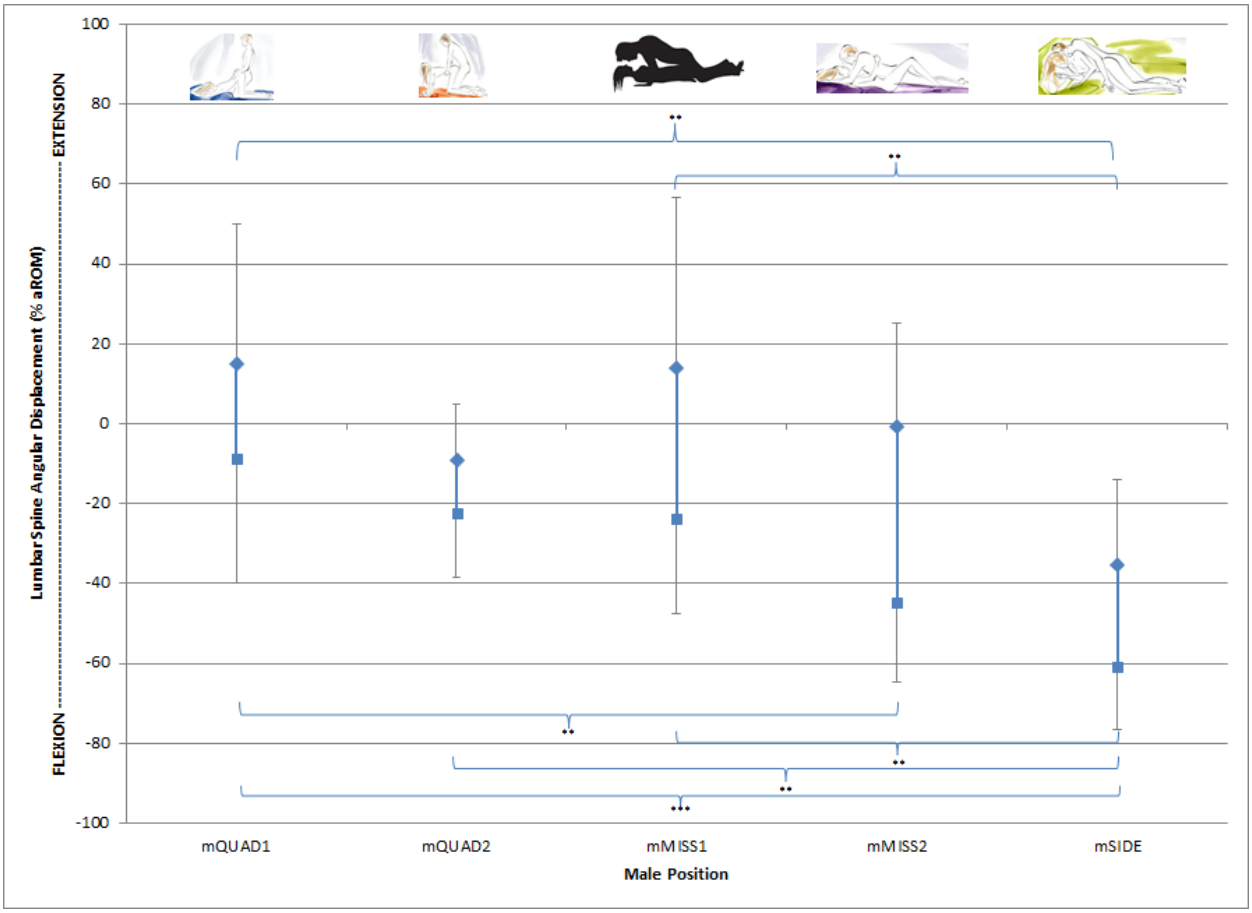


Fig. 15. Average maximum, minimum, and amplitude difference findings for male lumbar spine kinematics across all coital positions.

Values are expressed as a percentage of lumbar spine aROM achieved during each coital position. The highest and lowest points in the figure for each position are the average maximum and minimum percentage of lumbar spine aROM values achieved across all penetration cycles. The connecting solid blue line represents the average amplitude difference for each position across all penetration cycles. The positive vertical error bars represent one standard deviation of the mean average maximum values and the negative vertical error bars represent one standard deviation of the mean average minimum values. Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$.

The same trend as average minimum values above was seen for the percentages of lumbar spine aROM values at amplitude probabilities of 0.1, 0.5, and 0.9 (Fig. 16). mSIDE values were lowest (-65.40 ± 15.37, -54.55 ± 16.55, and -39.43 ± 19.30 % aROM, respectively) followed by both variations of PRONE, mMISS2 (-49.97 ± 19.91, -31.79 ± 21.07, and -7.02 ± 25.04 % aROM, respectively) and mMISS1 (-28.58 ± 22.33, -15.29 ± 25.18, and 5.07 ± 38.75 % aROM, respectively), and both variations of mQUAD, mQUAD2 (-24.95 ± 15.60, -12.54 ± 21.02, and -.78 ± 27.15 % aROM, respectively) and mQUAD1 (-22.01 ± 21.61, -9.90 ± 26.16, and 5.55 ± 35.84 % aROM). Significant differences were found at amplitude probabilities of 0.1 (F=17.006, p<.001), 0.5 (F=12.893, p<.001), and 0.9 (F=5.438, p=.002). At all three amplitude probabilities, mSIDE was significantly different from mQUAD1 (p<.001, p<.001, and p=.003, respectively),

mQUAD2 (p<.001, p<.001, and p=.013, respectively), and mMISS1 (p<.001, p<.001, and p=.004, respectively). At an amplitude probability of 0.1, mMISS2 was significantly different from mQUAD1 (p=.001), mQUAD2 (p=.004), and mMISS1 (p=.021). At an amplitude probability of 0.5, mMISS2 was significantly different from mQUAD1 (p=.040) and mSIDE (p=.030).

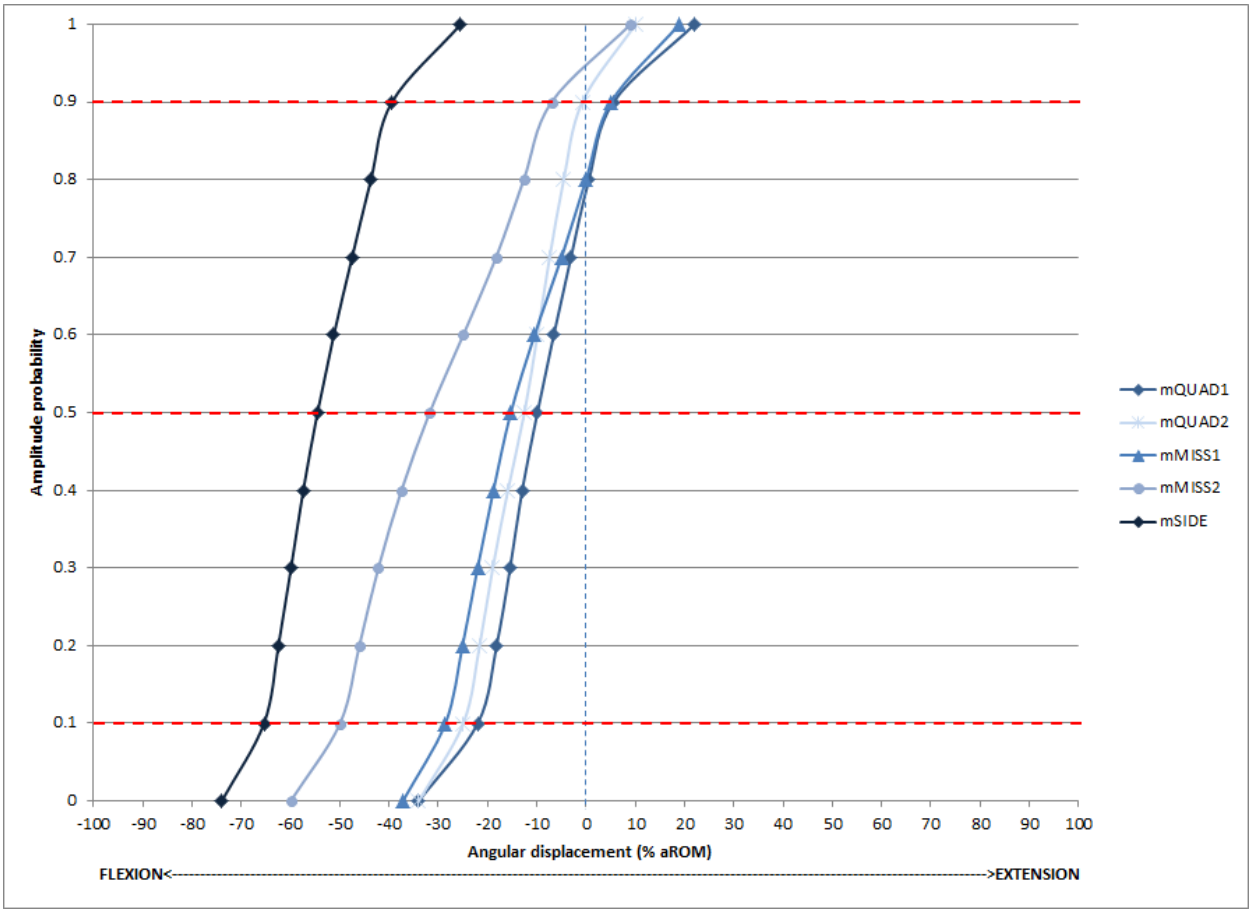


Fig. 16. APDF results for male spine kinematics across all coital positions.
Note that the APDF values are expressed as a percentage of total lumbar spine aROM. The angular displacement values (% aROM) at each amplitude probability indicates the probability that spine motion was equal to or lower than that % aROM value during that coital position. For example, 50 percent of the time during mMISS2, spine motion was equal to or less than approximately 32 percent of lumbar spine flexion aROM. The three dashed red lines indicate the amplitude probability levels at which statistical tests were performed.

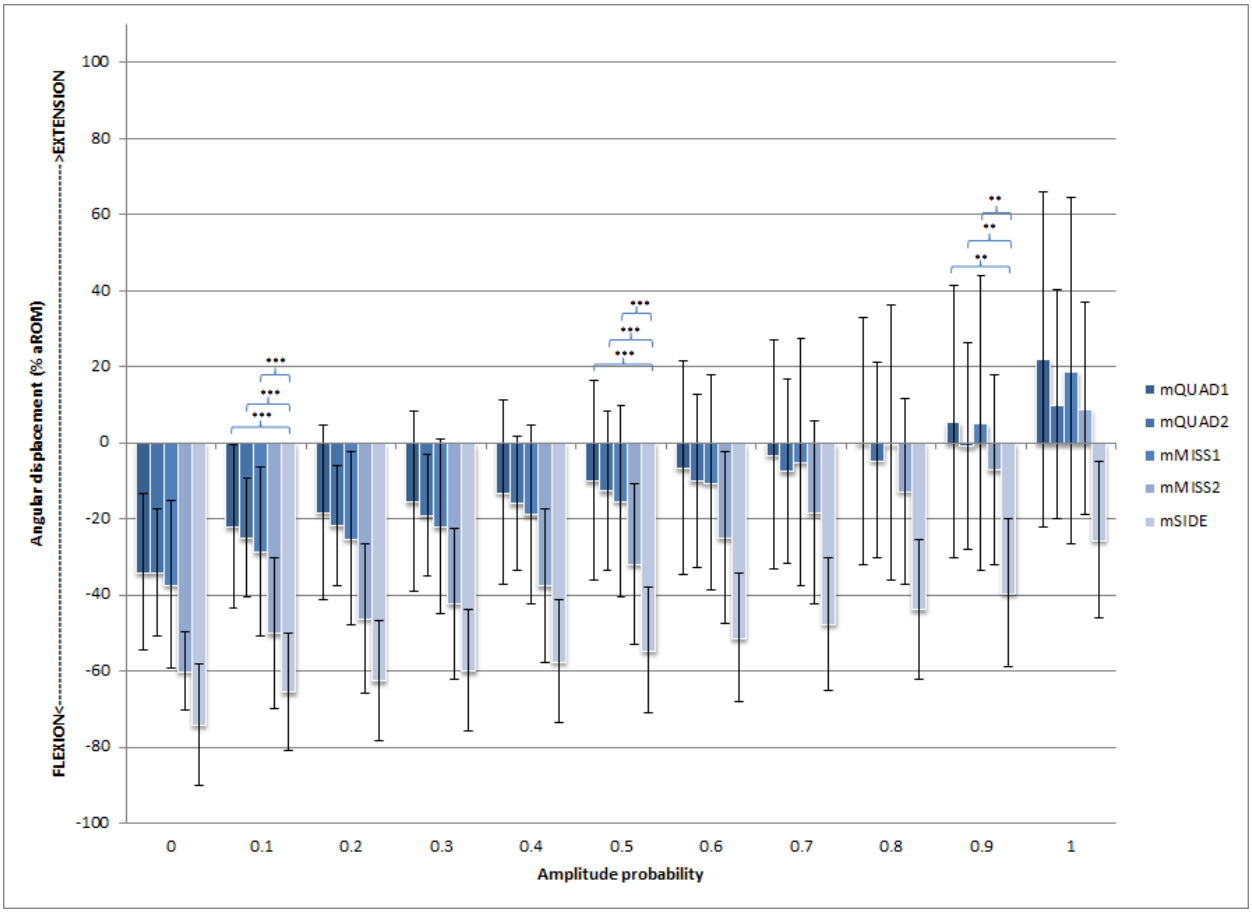


Fig. 17. Demonstration of subject variability for APDF results for male spine kinematics across all coital positions.
The vertical error bars represent one standard deviation of the average angular displacement at each amplitude probability for each coital position. A general linear model was only performed on amplitude probabilities of 0.1, 0.5, and 0.9, so statistical significance is only indicated for these three amplitude probabilities in the figure above. Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$.

4.1.1.1.2 Hip

A summary of male hip kinematic results discussed below can be found in Table 12, Table 13, Table 14, Table 15, and Table 16 within Appendix B.

The average maximum percentage of hip aROM achieved (Fig. 18) was highest for mMISS1 (56.38 ± 36.13 % aROM), followed by both variations of mQUAD, mQUAD2 (14.81 ± 26.24 % aROM) and mQUAD1 (13.89 ± 23.16 % aROM), mMISS2 (8.71 ± 27.21 % aROM), and mSIDE (5.53 ± 26.33 % aROM). All values were within hip extension ROM. Significant differences were found (F=8.365, p<.001) between mMISS1 and the following: mQUAD1 (p=.001), mQUAD2 (p=.001), mMISS2 (p<.001), and mSIDE (p<.001).

The average minimum percentage of hip aROM achieved (Fig. 18) was highest, again, for mMISS1 (-10.53 ± 20.16 % aROM), followed by both variations of mQUAD, mQUAD1 (-11.58

± 21.10 % aROM) and mQUAD2 (-11.71 ± 20.78 % aROM), mSIDE (-31.38 ± 10.15 % aROM), and mMISS2 (-36.14 ± 15.89 % aROM). Similar to the findings above for average maximum, mMISS1 had the highest (i.e., least flexion) value and mSIDE and mMISS2 had the lowest (i.e., most flexion) values. All values were within hip flexion ROM. mSIDE was significantly different (F=9.672, p<.001) from both variations of mQUAD, mQUAD1 (p=.009) and mQUAD2 (p=.010) as well as mMISS1 (p=.007). mMISS2 was also significantly different from both variations of mQUAD, mQUAD1 (p=.001), mQUAD2 (p=.001), and mMISS1 (p=.001).

The average amplitude difference between maximum and minimum percentages of hip aROM within a penetration cycle, across all cycles, (Fig. 18) was highest for both variations of PRONE, mMISS1 (67.03 ± 21.16 % aROM) and mMISS2 (44.81 ± 21.92 % aROM), followed by mSIDE (36.90 ± 31.44 % aROM), and both variations of mQUAD, mQUAD2 (26.51 ± 12.20 % aROM) and mQUAD1 (25.55 ± 9.27 % aROM). mMISS1 was found to be significantly different (F=8.539, p<.001) from mQUAD1 (p<.001), mQUAD2 (p<.001), and mSIDE (p=.004).

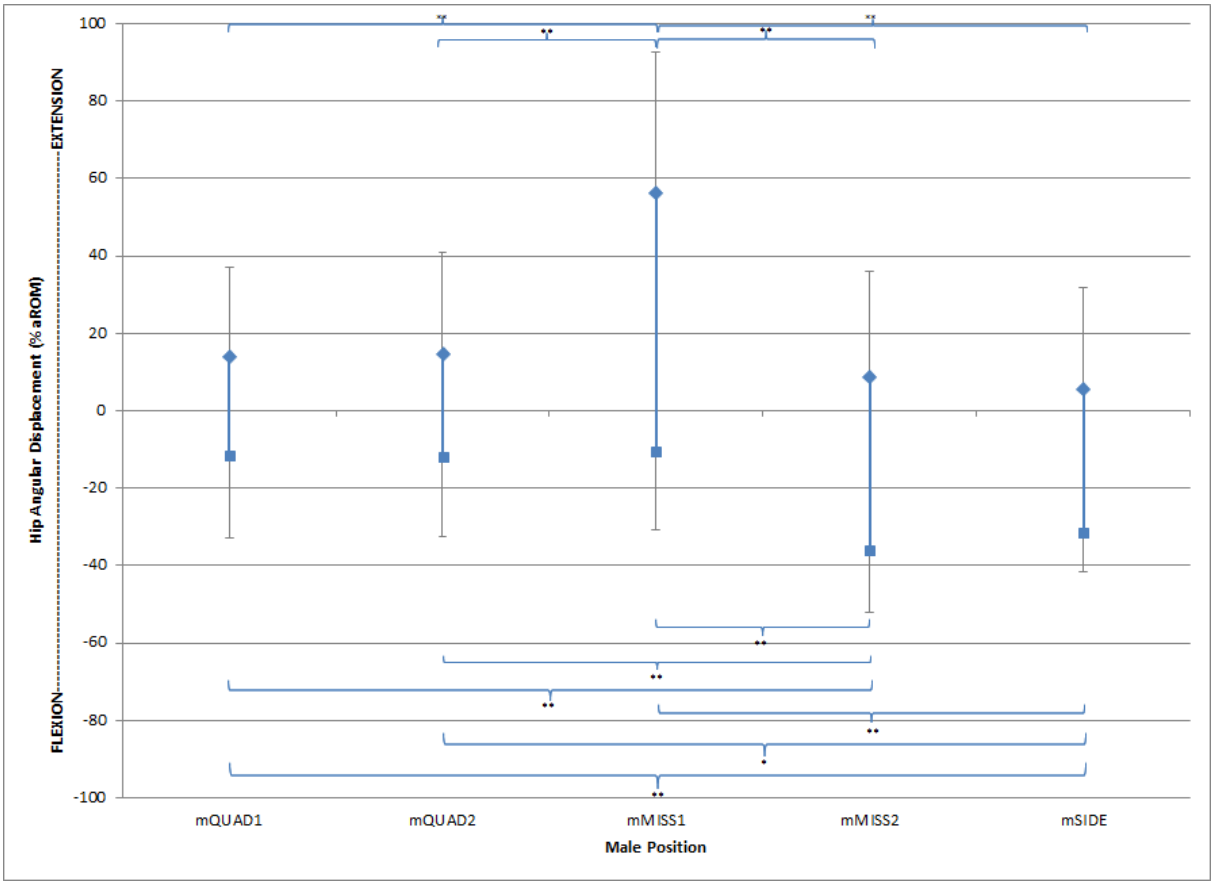


Fig. 18. Average maximum, minimum, and amplitude difference findings for male hip kinematics across all coital positions.

The positive vertical error bars represent one standard deviation of the mean average maximum values and the negative vertical error bars represent one standard deviation of the mean average minimum values. Statistical significance is represented by the following: $^{*}p$<.05, $^{**}p$<.01, $^{***}p$<.001.

The same trend as average minimum values above was seen for the percentages of hip aROM values at amplitude probabilities of 0.1, 0.5, and 0.9 (Fig. 19). mMISS1 values were highest (-4.44 ± 21.57 % aROM, 23.28 ± 33.54 % aROM, and 58.65 ± 37.12 % aROM, respectively), followed by both variations of mQUAD, mQUAD1 (-7.79 ± 19.84 % aROM, 3.09 ± 21.38 % aROM, and 19.49 ± 25.22 % aROM, respectively) and mQUAD2 (-8.07 ± 19.64 % aROM, 4.05 ± 21.99 % aROM, and 19.78 ± 27.30 % aROM, respectively), mSIDE (-26.23 ± 9.93 % aROM, -10.97 ± 11.11 % aROM, and 9.42 ± 25.66 % aROM, respectively), and mMISS2 (-30.49 ± 15.85 % aROM, -12.94 ± 13.88 % aROM, and 12.25 ± 25.67 % aROM, respectively). Significant differences were found at amplitude probabilities of 0.1 (F=9.668, p<.001), 0.5 (F=8.991, p<.001), and 0.9 (F=7.464, p<.001). At all three amplitude probabilities, mMISS1 was significantly different from mMISS2 (p<.001, p<.001, and p<.001, respectively) and mSIDE (p=.003, p<.001, and p<.001, respectively). mMISS1 was also significantly different from mQUAD1 and mQUAD2 at amplitude probabilities of 0.5 (p=.034 and p=.048, respectively) and 0.9 (p=.002 and p=.003, respectively). At an amplitude probability of 0.1, mMISS2 and mSIDE were significantly different from mQUAD1 (p=.001 and p=.012, respectively) and mQUAD2 (p=.002 and p=.014, respectively).

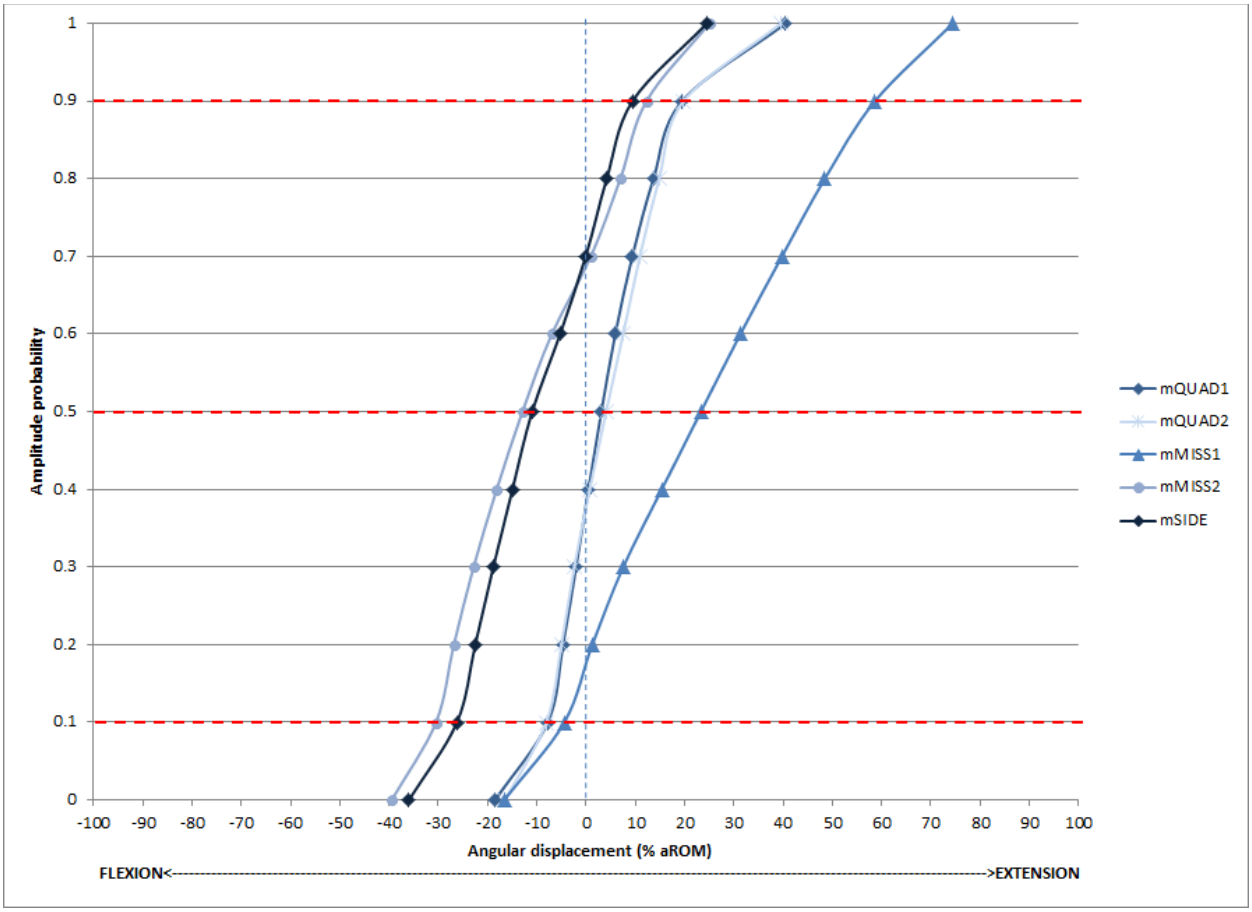


Fig. 19. APDF results for male hip kinematics across all coital positions.
The three dashed red lines indicate the amplitude probability levels at which statistical tests were performed.

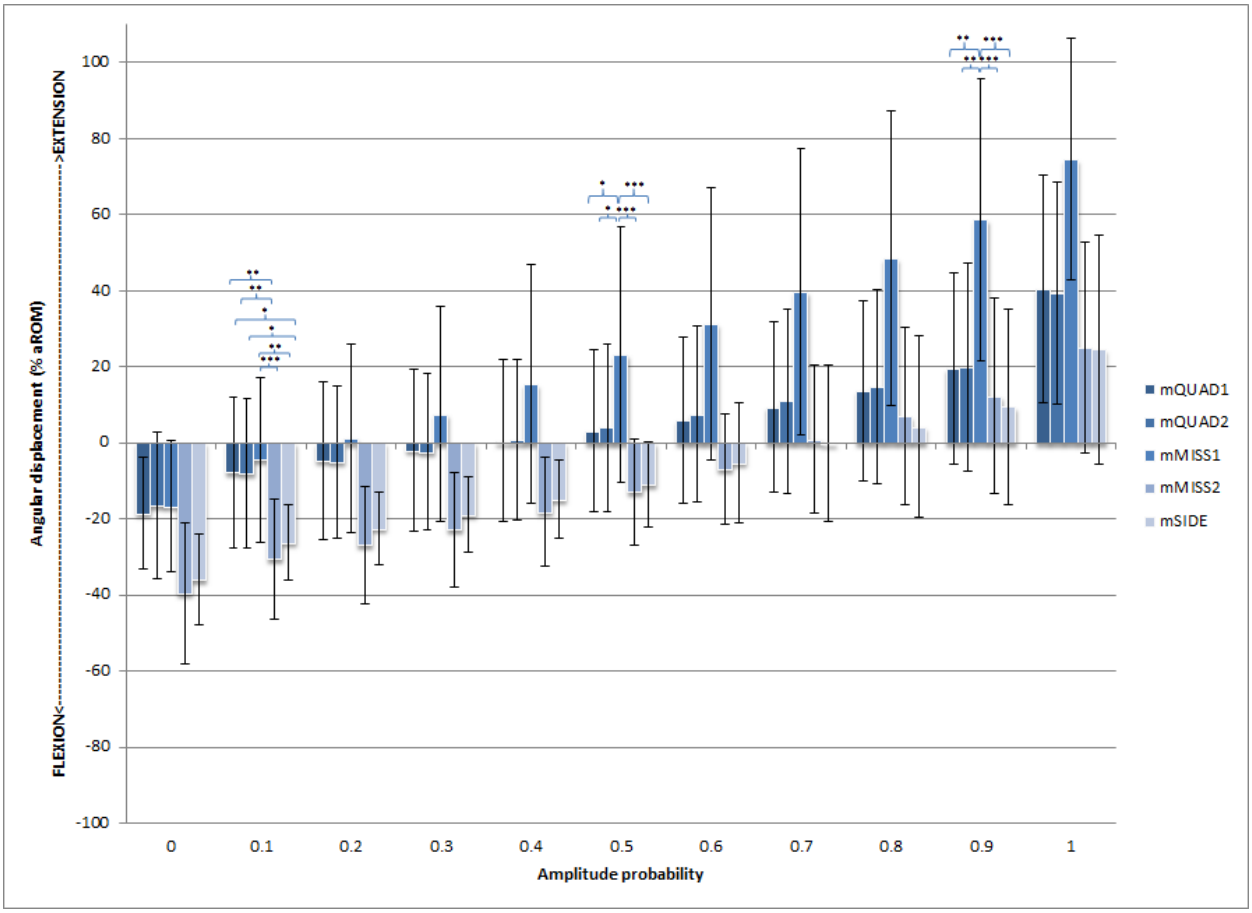


Fig. 20. Demonstration of subject variability for APDF results for male hip kinematics across all coital positions.
The vertical error bars represent one standard deviation of the average angular displacement at each amplitude probability for each coital position. A general linear model was only performed on amplitude probabilities of 0.1, 0.5, and 0.9, so statistical significance is only indicated for these three amplitude probabilities in the figure above. Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$.

4.1.1.2 Female

4.1.1.2.1 Lumbar spine

A summary of female lumbar spine kinematic results discussed below can be found in Table 22, Table 23, Table 24, Table 25, and Table 26, which can be found in Appendix B.

Female lumbar spine movement also varied depending on the coital position (Fig. 21); however, in contrast to male lumbar spine findings above, the majority of the range of motion used was in extension with the exception of both fMISS variations, fMISS2 (-44.42 ± 14.47 % aROM to -62.34 ± 16.91 % aROM) and fMISS1 (-22.01 ± 17.78 % aROM to -43.78 ± 14.57 % aROM). The average maximum and minimum percentage of lumbar spine aROM for the other three positions, fSIDE (12.09 ± 36.67 % aROM to 33.40 ± 36.56 % aROM), fQUAD1 (.10 ±

44.93 % aROM to 36.61 ± 40.19 % aROM), and fQUAD2 (41.17 ± 43.49 % aROM to 66.72 ± 36.80 % aROM) had ranges of lumbar spine motion that remained within extension. Both variations of fQUAD, fQUAD1 and fQUAD2, and fSIDE had comparable minimum values – fMISS1 and fMISS2 were both significantly different from fSIDE (p=.009 and p<.001, respectively), fQUAD1 (p=.006 and p<.001, respectively), and fQUAD2 (p<.001 and p<.001, respectively) (F=17.744, p<.001). For the average maximum values, fMISS1 and fMISS2 were, again, both significantly different from fSIDE (p =.005 and p <.001, respectively), fQUAD1 (p=.046 and p =.001, respectively), and fQUAD2 (p <.001 and p <.001, respectively) (F=16.439, p<.001). Both variations of fQUAD had significantly different maximum values, with fQUAD2 being significantly higher in extension than fQUAD1 (p=.043).

The average amplitude difference between maximum and minimum percentages of lumbar spine aROM within a penetration cycle, across all cycles, (Fig. 21) was highest for both variations of fQUAD, fQUAD1 (36.49 ± 48.66 % aROM) and fQUAD2 (25.51 ± 27.31 % aROM), followed by fSIDE (21.39 ± 9.72 % aROM), and both variations of fMISS, fMISS1 (21.70 ± 13.61 % aROM) and fMISS2 (17.86 ± 10.27 % aROM). This is a similar trend to the average minimum values above – both variations of fMISS had the lowest values, followed by fSIDE and both variations of fQUAD. There were no significant differences between positions (F=.946, p=.453).

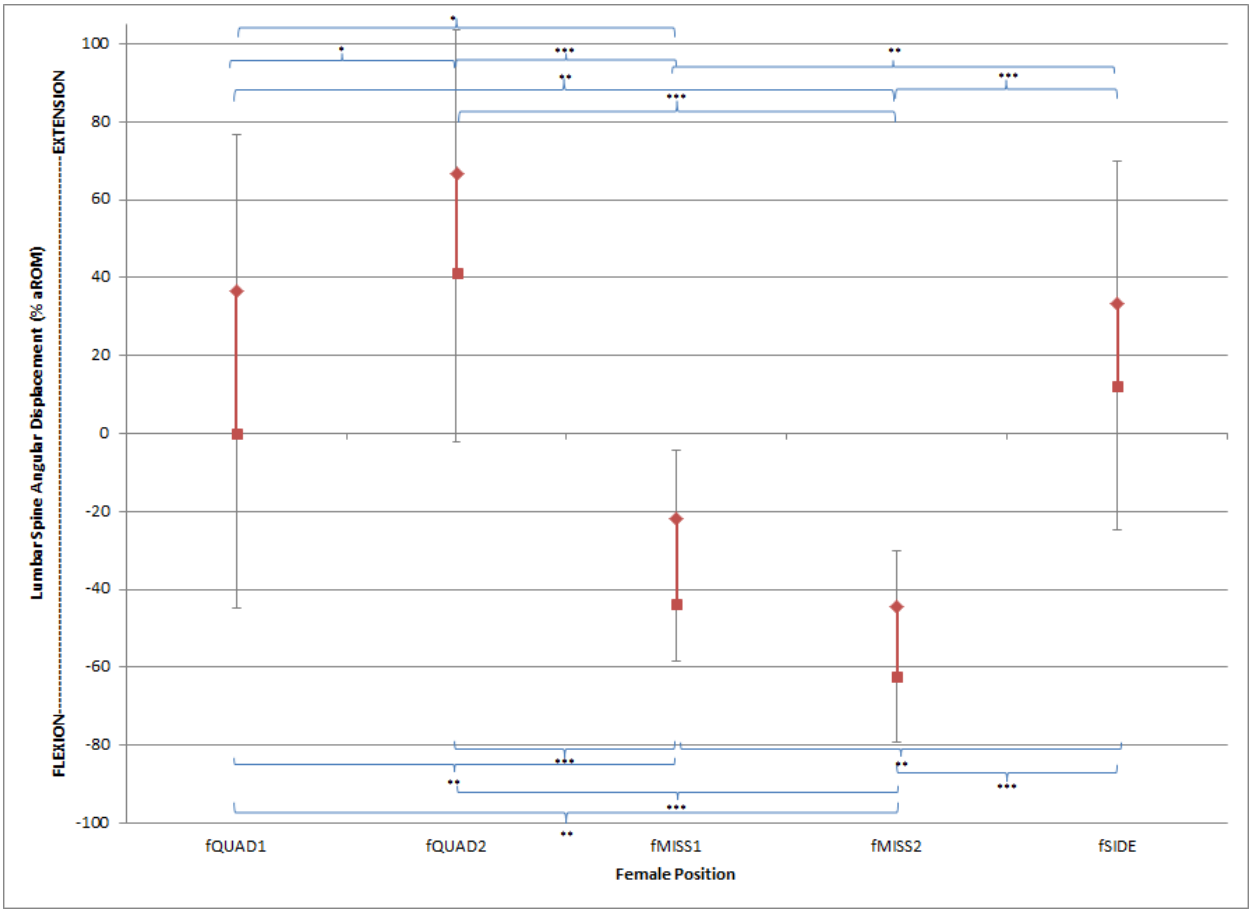


Fig. 21. Average maximum, minimum, and amplitude difference findings for female lumbar spine kinematics across all coital positions**.**

The positive vertical error bars represent one standard deviation of the mean average maximum values and the negative vertical error bars represent one standard deviation of the mean average minimum values. Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$.

The same trend as average maximum values above was seen for the percentages of lumbar spine aROM values at amplitude probabilities of 0.1, 0.5, and 0.9 (Fig. 22). fMISS2 values were lowest (-58.29 ± 17.41 % aROM, -50.70 ± 16.13 % aROM, and -38.80 ± 13.70 % aROM, respectively), followed by fMISS1 (-40.16 ± 15.36 % aROM, -28.16 ± 13.04 % aROM, and -15.59 ± 15.92 % aROM, respectively), fQUAD1 (-4.03 ± 40.84 % aROM, 14.35 ± 40.76 % aROM, and 35.29 ± 43.99 % aROM, respectively), fSIDE (12.30 ± 34.38 % aROM, 26.65 ± 35.97 % aROM, and 38.51 ± 37.36 % aROM, respectively), and fQUAD2 (29.96 ± 46.25 % aROM, 52.40 ± 44.45 % aROM, and 67.49 ± 45.65 % aROM, respectively). Significant differences were found at amplitude probabilities of 0.1 (F=15.564, p<.001), 0.5 (F=19.805, p<.001), and 0.9 (F=18.853, p<.001). At all three amplitude probabilities, fMISS2 was significantly different from fQUAD1 (p=.001, p<.001, and p<.001, respectively), fQUAD2 (p<.001, p<.001, and p<.001, respectively), and fSIDE (p<.001, p<.001, and p<.001, respectively) and fMISS1 was significantly different from fQUAD2 (p<.001, p<.001, and

p<.001, respectively) and fSIDE (p=.005, p=.004, and p=.010, respectively). fMISS1 was also significantly different from fQUAD1 at amplitude probabilities of 0.5 (p=.039) and 0.9 (p=.017). fQUAD1 was significantly different from fQUAD2 at an amplitude probability of 0.5 (p=.031).

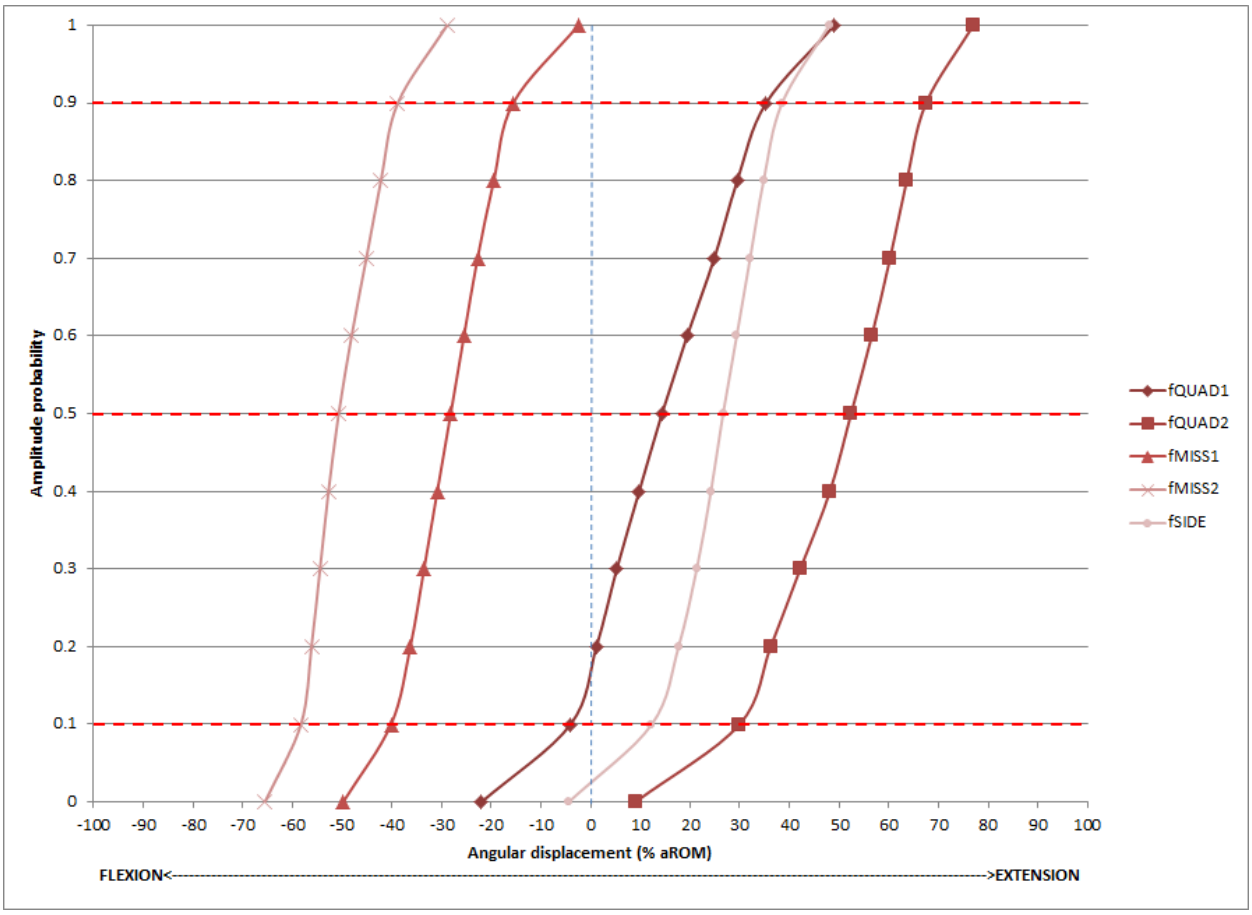


Fig. 22. APDF results for female spine kinematics across all coital positions.
The three dashed red lines indicate the amplitude probability levels at which statistical tests were performed.

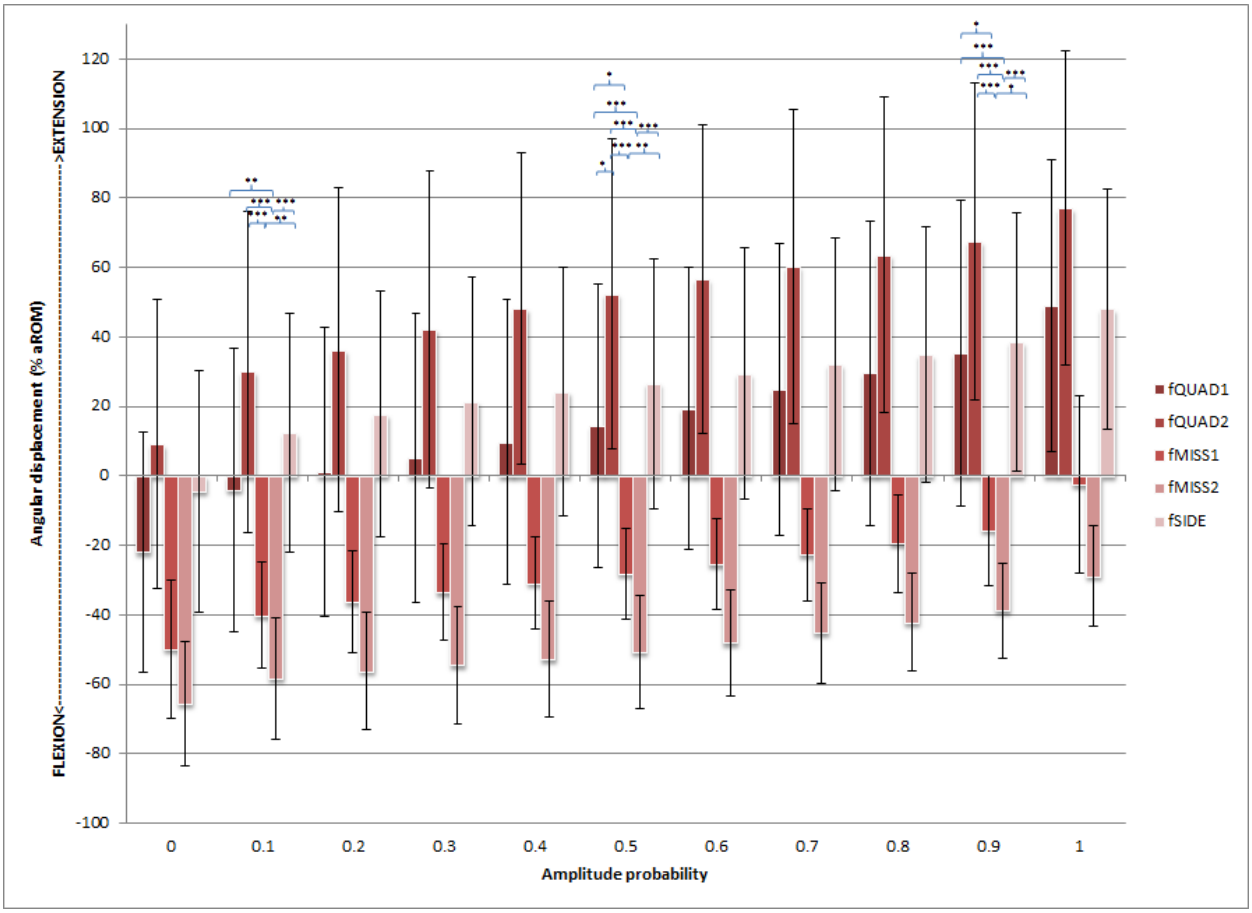


Fig. 23. Demonstration of subject variability for APDF results for female spine kinematics across all coital positions.

The vertical error bars represent one standard deviation of the average angular displacement at each amplitude probability for each coital position. A general linear model was only performed on amplitude probabilities of 0.1, 0.5, and 0.9, so statistical significance is only indicated for these three amplitude probabilities in the figure above. Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$.

4.1.1.2.2 Hip

A summary of female hip kinematic results discussed below can be found in Table 27, Table 28, Table 29, Table 30, and Table 31, which can be found in Appendix B.

The average maximum percentage of hip aROM achieved (Fig. 24) was highest for fMISS1 (-4.27 ± 25.84 % aROM), followed by fMISS2 (-32.52 ± 25.89 % aROM), fSIDE (-62.88 ± 16.88 % aROM), and both variations of fQUAD, fQUAD2 (-63.67 ± 16.78 % aROM) and fQUAD1 (-73.35 ± 13.12 % aROM). All values remained within flexion ROM, but fMISS1 was close to neutral (i.e., 0 % aROM). fMISS1 was found to be significantly different (F=20.654, p<.001) from fQUAD1 (p <.001), fQUAD2 (p<.001), fMISS2 (p=.036) and fSIDE (p<.001). fMISS2 was also found to be significantly different from the other four positions, including fMISS1, fQUAD1 (p <.001), fQUAD2 (p=.002), and fSIDE (p=.002)

The same trend as average maximum values above was seen for the average minimum percentage of hip aROM achieved (Fig. 24). fMISS1 (-18.32 ± 19.97) had the highest value, followed by fMISS2 (-44.40 ± -45.28), fSIDE (-69.43 ± 17.61), and both variations of fQUAD, fQUAD2 (-70.52 ± 16.88) and fQUAD1 (-81.20 ± 12.81). Similar to the findings above for the average maximum, all values remained within flexion ROM, both variations of fMISS had the highest values (i.e., least flexion) and both variations of fQUAD had the lowest values (i.e., most flexion). Once again, significant differences were found (F=24.702, p<.001) between fMISS1 and fQUAD1 (p<.001), fQUAD2 (p<.001), fMISS2 (p=.015) and fSIDE (p<.001). fMISS2 was also found to be significantly different from all other positions, including fMISS1, fQUAD1 (p<.001), fQUAD2 (p=.002), and fSIDE (p=.002).

The average amplitude difference between maximum and minimum percentages of hip aROM within a penetration cycle, across all cycles, (Fig. 24) was highest for both variations of fMISS, fMISS1 (14.07 ± 11.37 % aROM) and fMISS2 (11.91 ± 11.66 % aROM), followed by both variations of fQUAD, fQUAD1 (7.83 ± 3.30 % aROM) and fQUAD2 (6.83 ± 2.30 % aROM) and fSIDE (6.57 ± 2.70 % aROM). There were no significant differences found between positions (F=1.641, p=.194).

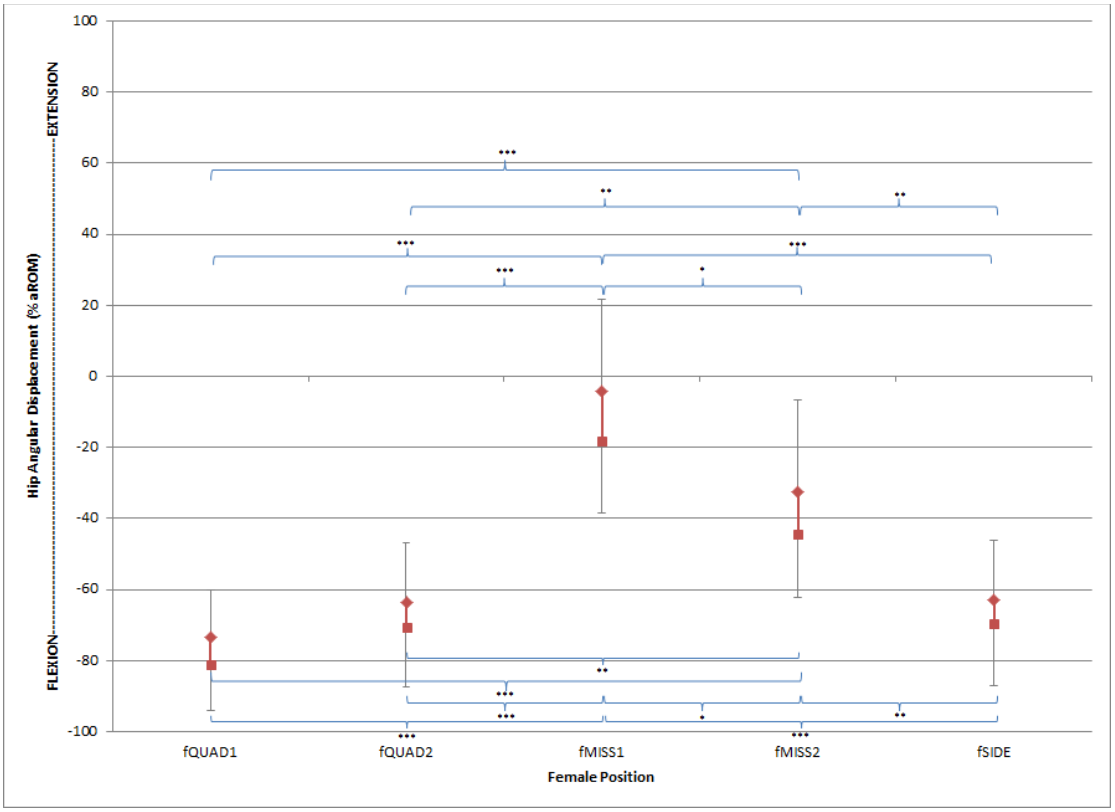


Fig. 24. Average maximum, minimum, and amplitude difference findings for female hip kinematics across all coital positions.

The positive vertical error bars represent one standard deviation of the mean average maximum values and the negative vertical error bars represent one standard deviation of the mean average minimum values. Statistical significance is represented by the following: $^{*}p$<.05, $^{**}p$<.01, $^{***}p$<.001.

The same trend as average maximum and minimum values above was seen for the percentages of hip aROM values at amplitude probabilities of 0.1, 0.5, and 0.9 (Fig. 25). fMISS1 values were highest (-8.31 ± 19.18 % aROM, -1.44 ± 21.61 % aROM, and 8.46 ± 27.27 % aROM, respectively), followed by fMISS2 (-41.17 ± 17.10 % aROM, -35.13 ± 19.06 % aROM, and -26.98 ± 26.65 % aROM, respectively), fSIDE(-66.09 ± 17.66 % aROM, -61.31 ± 17.38 % aROM, and -56.20 ± 17.25 % aROM, respectively), and both variations of fQUAD, fQUAD2 (-66.29 ± 15.61 % aROM, -61.36 ± 16.04 % aROM, and -56.44 ± 16.24 % aROM, respectively) and fQUAD1 (-78.84 ± 12.25 % aROM, -72.76 ± 12.12 % aROM, and -67.45 ± 12.75% aROM, respectively). Significant differences were found at amplitude probabilities of 0.1 (F=35.001, p<.001), 0.5 (F=31.537, p<.001), and 0.9 (F=25.457, p<.001). At all three amplitude probabilities, fMISS1 was significantly different from all other positions, including fQUAD1 (p<.001, p<.001, and p<.001, respectively), fQUAD2 (p<.001, p<.001, and p<.001, respectively), fMISS2 (p<.001, p=.001, and p=.004, respectively), and fSIDE (p<.001, p<.001, and p<.001, respectively). fMISS2 was also significantly different from all other positions at all three amplitude probabilities, including fQUAD1 (p<.001, p<.001, and p<.001, respectively), fQUAD2 (p=.002, p=.003, and p=.006, respectively), fMISS1, and fSIDE (p=.003, p=.003, and p=.007, respectively).

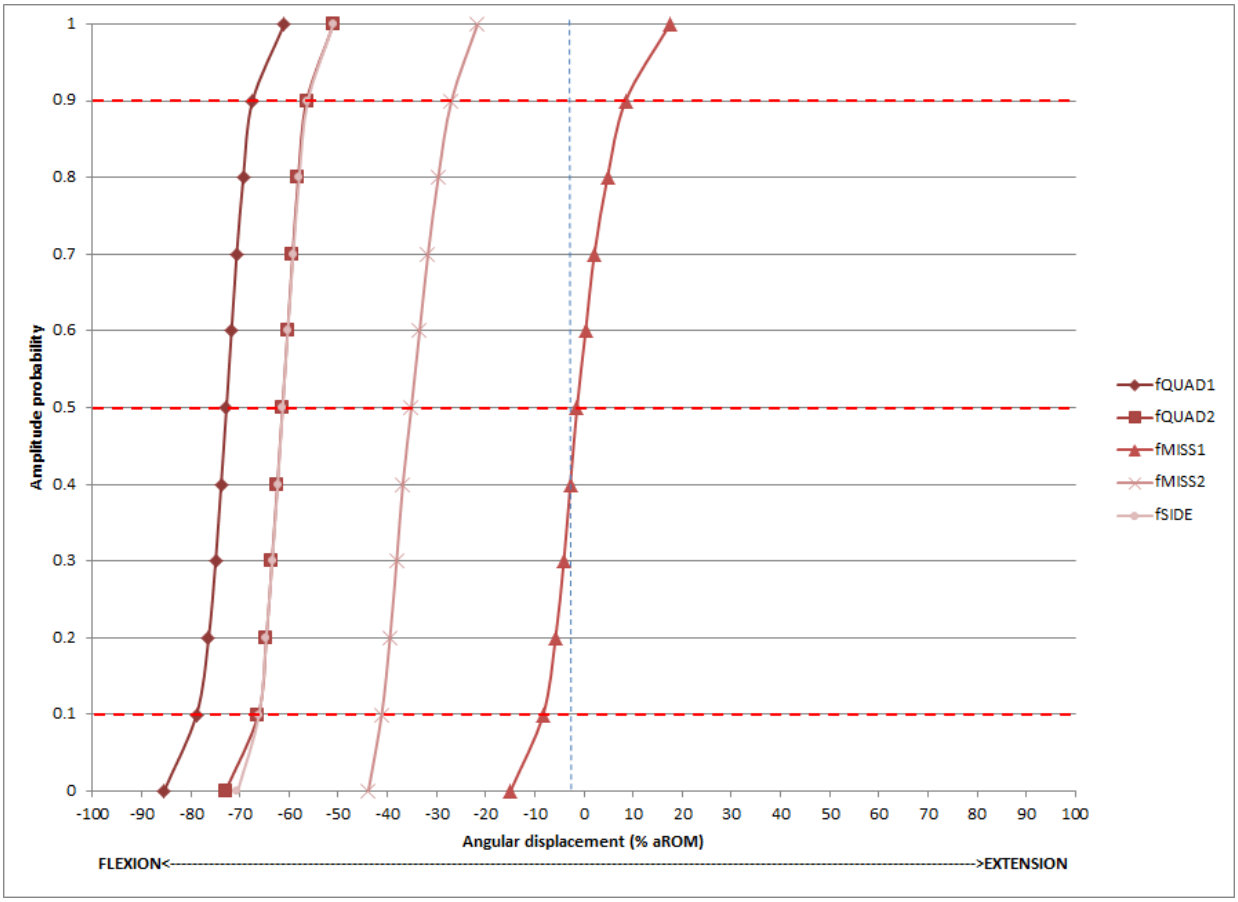


Fig. 25. APDF results for female hip kinematics across all coital positions.
The three dashed red lines indicate the amplitude probability levels at which statistical tests were performed.

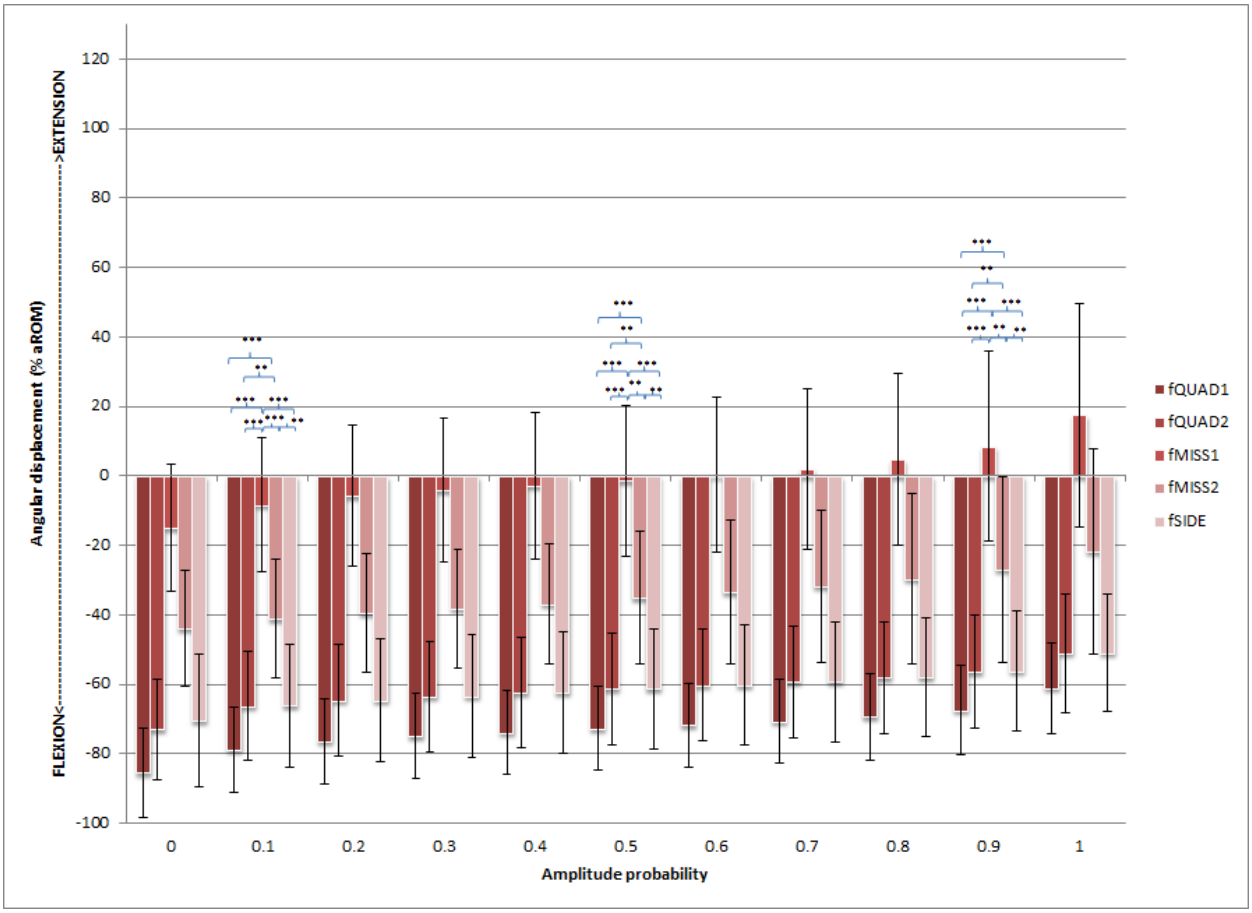


Fig. 26. Demonstration of subject variability for APDF results for female hip kinematics across all coital positions.
The vertical error bars represent one standard deviation of the average angular displacement at each amplitude probability for each coital position. A general linear model was only performed on amplitude probabilities of 0.1, 0.5, and 0.9, so statistical significance is only indicated for these three amplitude probabilities in the figure above. Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$.

4.1.2 Electromyography

4.1.2.1 Male

A summary of male EMG results discussed below can be found in Table 17, Table 18, Table 19, Table 20, and Table 21 in Appendix B.

4.1.2.1.1 Upper erector spinae

The maximum % MVC achieved during each coital position (Fig. 27) was highest for mSIDE (11.54 ± 8.28 % MVC), followed by both variations of mQUAD, mQUAD1 (10.71 ± 6.36 % MVC) and mQUAD2 (9.69 ± 6.98 % MVC), and both variations of PRONE, mMISS2 (5.72 ±

2.91 % MVC) and mMISS1 (5.21 ± 2.48 % MVC). All maximum values were under 15% MVC. No significant differences were found between positions (F=2.682, p=.047).

The same trend as average maximum values above was seen for the % MVC values at amplitude probabilities of 0.1, 0.5, and 0.9. mSIDE values were highest (1.82 ± 3.23 % MVC, 3.51 ± 4.37 % MVC, and 6.45 ± 6.19% MVC, respectively), followed by both variations of mQUAD, mQUAD1 (1.03 ± 1.26 % MVC, 2.17 ± 1.68 % MVC, and 5.00 ± 2.80 % MVC, respectively) and mQUAD2 (.78 ± 0.91 % MVC, 1.88 ± 1.67 % MVC, and 4.76 ± 3.11 % MVC, respectively), and both variations of PRONE, mMISS1 (.91 ± 0.58 % MVC, 1.67 ± .82 % MVC, and 2.97 ± 1.39 % MVC, respectively) and mMISS2 (1.02 ± .61 % MVC, 1.89 ± 0.95 % MVC, and 2.83 ± 1.89 % MVC, respectively). No significant differences were found at amplitude probabilities of 0.1 (F=.647, p=.634), 0.5 (F=1.222, p=.321), and 0.9 (F=1.996, p=.117).

4.1.2.1.2 Lower erector spinae

Similar to maximum values for UES, the maximum % MVC of LES achieved during each coital position (Fig. 27) was highest for both variations of mQUAD, mQUAD1 (20.15 ± 9.15 % MVC) and mQUAD2 (17.61 ± 6.88 % MVC), followed by mSIDE (12.15 ± 6.77 % MVC), and both variations of PRONE, mMISS2 (7.47 ± 5.71 % MVC) and mMISS1 (4.84 ± 3.29). Significant differences were found (F=12.704, p<.001) between mQUAD1 and mMISS1 (p<.001), mMISS2 (p<.001), and mSIDE (p=.027). mQUAD2 was also significantly different from mMISS1 (p<.001) and mMISS2 (p=.003).

The same trend as average maximum values above was seen for the % MVC values at amplitude probabilities of 0.1, 0.5, and 0.9. Both variations of mQUAD, mQUAD1 (2.34 ± 2.27 % MVC, 5.75 ± 3.38 % MVC, and 11.64 ± 5.19 % MVC, respectively) and mQUAD2 (2.35 ± 2.02 % MVC, 5.06 ± 2.74 % MVC, and 10.84 ± 3.88 % MVC, respectively), had the highest values, followed by mSIDE (1.04 ± .84 % MVC, 2.11 ± 1.78 % MVC, and 5.15 ± 4.19 % MVC, respectively), and both variations of PRONE, mMISS2 (.55 ± .38 % MVC, 1.09 ± .84 % MVC, and 2.41 ± 2.04% MVC, respectively) and mMISS1 (.59 ± 0.54 % MVC, 1.15 ± 0.97 % MVC, and 2.15 ± 1.89 % MVC, respectively). Significant differences were found at amplitude probabilities of 0.1 (F=9.728, p<.001), 0.5 (F=21.743, p<.001), and 0.9 (F=21.047, p<.001). At all three amplitude probabilities, mQUAD1 was found to be significantly different from mMISS1 (p=.002, p<.001, and p<.001, respectively), mMISS2 (p=.002, p<.001, and p<.001, respectively), and mSIDE (p=.037, p<.001, and p<.001) and mQUAD2 was also found to be significantly different from mMISS1 (p=.004, p<.001, and p<.001, respectively), mMISS2 (p=.003, p<.001, and p<.001, respectively), and mSIDE (p=.046, p=.001, and p=.002, respectively).

4.1.2.1.3 Latissimus dorsi

The maximum % MVC of LD achieved during each coital position (Fig. 27) was highest for mSIDE (33.52 ± 31.34% MVC), followed by mQUAD1 (32.88 ± 44.84 % MVC), mMISS2 (27.24 ± 36.07 % MVC), mQUAD2 (21.03 ± 21.07 % MVC), and mMISS1 (13.44 ± 12.08 % MVC). No significant differences were found between positions (F=1.928, p=.128).

The same trend as average maximum values above was seen for the % MVC values at amplitude probabilities of 0.1, 0.5, and 0.9. mSIDE had the highest values (9.51 ± 20.12 % MVC, 15.07 ± 23.49 % MVC, and 22.70 ± 27.15 % MVC, respectively), followed by mQUAD1 (1.75 ± 1.79 % MVC, 7.70 ± 10.27 % MVC, and 17.71 ± 23.21 % MVC, respectively), mMISS2 (6.80 ± 8.72 % MVC, 10.85 ± 14.09 % MVC, and 16.06 ± 20.27 % MVC, respectively), mQUAD2 (1.47 ± 1.63 % MVC, 5.32 ± 5.89 % MVC, and 11.54 ± 13.07 % MVC, respectively), and mMISS1 (2.93 ± 2.71 % MVC, 5.63 ± 5.25 % MVC, and 8.86 ± 8.65 % MVC, respectively). No significant differences were found at amplitude probabilities of 0.1 (F=1.505, p=.222), 0.5 (F=1.380, p=.261), and 0.9 (F=1.659, p=.181).

4.1.2.1.4 Rectus abdominus

The maximum % MVC of RA achieved during each coital position (Fig. 27) showed a reverse trend in comparison to UES and LES and was highest for both variations of PRONE, mMISS1 (37.22 ± 21.17 % MVC) and mMISS2 (33.93 ± 23.67 % MVC), followed by mSIDE (17.38 ± 11.91 % MVC), and both variations of mQUAD, mQUAD1 (8.48 ± 8.28 % MVC) and mQUAD2 (7.63 ± 5.17 % MVC). Significant differences were found (F=10.364, p<.001) between mMISS1 and mQUAD1 (p<.001), mQUAD2 (p<.001), and mSIDE (p=.021) as well as between mMISS2 and mQUAD1 (p=.001) and mQUAD2 (p=.001).

The same trend as average maximum values above was seen for the % MVC values at amplitude probabilities of 0.1, 0.5, and 0.9. Both variations of PRONE, mMISS1 (6.28 ± 4.32 % MVC, 11.76 ± 8.83 % MVC, and 23.79 ± 17.05 % MVC, respectively) and mMISS2 (1.38 ± 1.25 % MVC, 5.73 ± 6.07 % MVC, and 17.40 ± 15.17 % MVC), had the highest values, followed by mSIDE (1.45 ± 1.79 % MVC, 3.12 ± 3.05 % MVC, and 8.29 ± 5.79 % MVC, respectively), and both variations of mQUAD, mQUAD1 (1.43 ± 0.99 % MVC, 2.32 ± 2.38 % MVC, and 4.82 ± 5.36 % MVC, respectively) and mQUAD2 (1.12 ± 1.00 % MVC, 1.94 ± 1.60 % MVC, and 3.81 ± 3.13 % MVC, respectively). Significant differences were found at amplitude probabilities of 0.1 (F=8.081, p<.001), 0.5 (F=8.652, p<.001), and 0.9 (F=8.460, p<.001). At all three amplitude probabilities, mMISS1 was significantly different from mQUAD1 (p=.001, p<.001, and p<.001), mQUAD2 (p<.001, p<.001, and p<.001), and mSIDE (p<.001, p<.001, and p=.005). At amplitude probabilities of 0.1 and 0.5 mMISS1 was also significantly different from mMISS2 (p<.001 and p=.020, respectively). mMISS2 was also significantly different from mQUAD1 (p=.025) and mQUAD2 (p=.013) at an amplitude probability of 0.9.

4.1.2.1.5 External oblique

The same trend as RA results above was seen for the maximum % MVC of EO achieved during each coital position (Fig. 27). Both variations of PRONE, mMISS1 (41.65 ± 29.95 % MVC) and mMISS2 (29.02 ± 22.51 % MVC) had the highest values, followed by mSIDE (16.35 ± 15.91 % MVC), and both variations of mQUAD, mQUAD1 (14.45 ± 14.12 % MVC) and mQUAD2 (14.89 ± 16.05 % MVC). mMISS1 was found to be significantly different from mQUAD1 (p<.001), mQUAD2 (p<.001), and mSIDE (p<.001) (F=8.923, p<.001).

The same trend as average maximum values above and RA results was seen for the % MVC values at amplitude probabilities of 0.1, 0.5, and 0.9. Both variations of PRONE, mMISS1 (8.25 ± 10.43 % MVC, 14.62 ± 13.07 % MVC, and 26.99 ± 21.55 % MVC, respectively) and mMISS2 (2.43 ± 2.48 % MVC, 6.98 ± 7.07 % MVC, and 16.07 ± 14.79 % MVC, respectively), had the highest values, followed by mSIDE (1.20 ± 0.93 % MVC, 3.25 ± 3.18 % MVC, and 9.07 ± 10.04 % MVC, respectively), and both variations of mQUAD, mQUAD1 (3.99 ± 5.47 % MVC, 6.03 ± 7.58 % MVC, and 9.03 ± 10.19 % MVC, respectively) and mQUAD2 (3.84 ± 5.41 % MVC, 6.03 ± 8.63 % MVC, and 8.69 ± 11.28 % MVC, respectively). Significant differences were found at amplitude probabilities of 0.1 (F=3.573, p=.016), 0.5 (F=6.238, p=.001), and 0.9 (F=8.232, p<.001). At amplitude probabilities of 0.5 and 0.9, mMISS1 was significantly different from mQUAD1 (p=.005 and p<.001, respectively), mQUAD2 (p=.005 and p<.001, respectively), mMISS2 (p=.014 and p=.037, respectively), and mSIDE (p<.001 and p<.001, respectively). At an amplitude probability of 0.1, mMISS1 was also significantly difference from mSIDE (p=.013).

4.1.2.1.6 Internal oblique

The maximum % MVC of IO achieved during each coital position (Fig. 27) was highest for both variations of mQUAD, mQUAD2 (42.22 ± 27.40 % MVC) and mQUAD1 (42.01 ± 27.04 % MVC), followed by both variations of PRONE, mMISS1 (33.20 ± 24.19 % MVC) and mMISS2 (32.98 ± 22.11 % MVC), and mSIDE (31.56 ± 24.33 % MVC). No significant differences were found between positions (F=.899, p=.475).

A similar trend to average maximum values above was seen for the % MVC values at amplitude probabilities of 0.1, 0.5, and 0.9. Both variations of mQUAD, mQUAD1 (9.29 ± 6.87 % MVC, 17.20 ± 14.45 % MVC, and 27.48 ± 20.38 % MVC, respectively) and mQUAD2 (8.54 ± 5.53 % MVC, 15.39 ± 9.70 % MVC, and 25.28 ± 16.80 % MVC, respectively), had the highest values, followed by both variations of PRONE, mMISS1 (5.99 ± 5.31 % MVC, 10.53 ± 7.52 % MVC, and 18.60 ± 13.13 % MVC, respectively) and mMISS2 (2.86 ± 3.41 % MVC, 7.74 ± 6.53 % MVC, and 16.51 ± 10.70 % MVC), and mSIDE (2.98 ± 2.05 % MVC, 7.45 ± 3.60% MVC, and 14.79 ± 6.99 % MVC, respectively). Significant differences were found at amplitude probabilities of 0.1 (F=5.647, p=.001) and 0.5 (F=3.845, p=.011), but not 0.9 (F=2.946, p=.034). At amplitude probabilities of 0.1 and 0.5, mQUAD1 was found to be significantly different from mMISS2 (p =.009 and p=.043, respectively) and mSIDE (p =.010 and p=.034, respectively). At an amplitude probability of 0.1, mQUAD2 was also found to be significantly different from mMISS2 (p =.025) and mSIDE (p =.029).

4.1.2.1.7 Gluteus maximus

The same trend as UES results above was seen for the maximum % MVC of GMax achieved during each coital position (Fig. 27). This value was highest for mSIDE (90.56 ± 126.44 % MVC), followed by both variations of mQUAD, mQUAD1 (69.86 ± 105.47 % MVC) and mQUAD2 (66.36 ± 83.52 % MVC), and both variations of PRONE, mMISS2 (65.03 ± 66.65 % MVC) and mMISS1 (46.86 ± 64.94 % MVC). No significant differences were found between positions (F=2.140, p=.099).

A similar trend to average maximum values above was seen for the % MVC values at amplitude probabilities of 0.1, 0.5, and 0.9 mQUAD1 (10.77 ± 24.31 % MVC, 21.38 ± 41.84 % MVC, and 41.79 ± 74.41% MVC, respectively) had the highest values, followed by mSIDE (2.46 ± 1.90 % MVC, 12.42 ± 15.83 % MVC, and 40.06 ± 62.53 % MVC, respectively), mQUAD2 (10.79 ± 22.21 % MVC, 20.31 ± 33.84 % MVC, and 37.98 ± 53.34 % MVC, respectively), and both variations of PRONE, mMISS2 (2.84 ± 2.52 % MVC, 3.95 ± 4.45 % MVC, and 28.37 ± 35.60 % MVC, respectively) and mMISS1 (2.16 ± 4.19 % MVC, 3.84 ± 5.87 % MVC, and 22.75 ± 38.63 % MVC, respectively). No significant differences were found at amplitude probabilities of 0.1 (F=1.312, p=.295), 0.5 (F=2.079, p=.108), and 0.9 (F=1.856, p=.143).

4.1.2.1.8 Biceps femoris

The maximum % MVC of BF achieved during each coital position (Fig. 27) was highest for mSIDE (37.68 ± 39.20 % MVC), followed by both variations of PRONE, mMISS2 (38.94 ± 60.63 % MVC) and mMISS1 (29.27 ± 38.80 % MVC), and both variations of mQUAD, mQUAD1 (9.54 ± 6.49 % MVC) and mQUAD2 (6.98 ± 4.29 % MVC). No significant differences were found between positions (F=3.374, p=.020).

The same trend as average maximum values above was seen for the % MVC values at amplitude probabilities of 0.1, 0.5, and 0.9. mSIDE (2.31 ± 2.14 % MVC, 8.11 ± 10.83 % MVC, and 21.48 ± 27.36 % MVC, respectively) had the highest values, followed by both variations of PRONE, mMISS2 (.76 ± .89 % MVC, 2.87 ± 3.55 % MVC, and 14.86 ± 18.79 % MVC, respectively) and mMISS1 (.70 ± .75 % MVC, 1.78 ± 1.61 % MVC, and 8.66 ± 8.62 % MVC, respectively), and both variations of mQUAD, mQUAD1 (1.24 ± .63 % MVC, 2.32 ± 1.08 % MVC, and 4.25 ± 2.46 % MVC, respectively) and mQUAD2 (1.17 ± 0.50 % MVC, 2.25 ± 0.92 % MVC, and 4.11 ± 2.37 % MVC, respectively). No significant differences were found at amplitude probabilities of 0.1 (F=2.960, p=.039) and 0.5 (F=2.946, p=.034); however, at an amplitude probability of 0.9 (F=3.829, p=.011), mSIDE was found to be significantly different from mQUAD1 (p=.024) and mQUAD2 (p=.022).

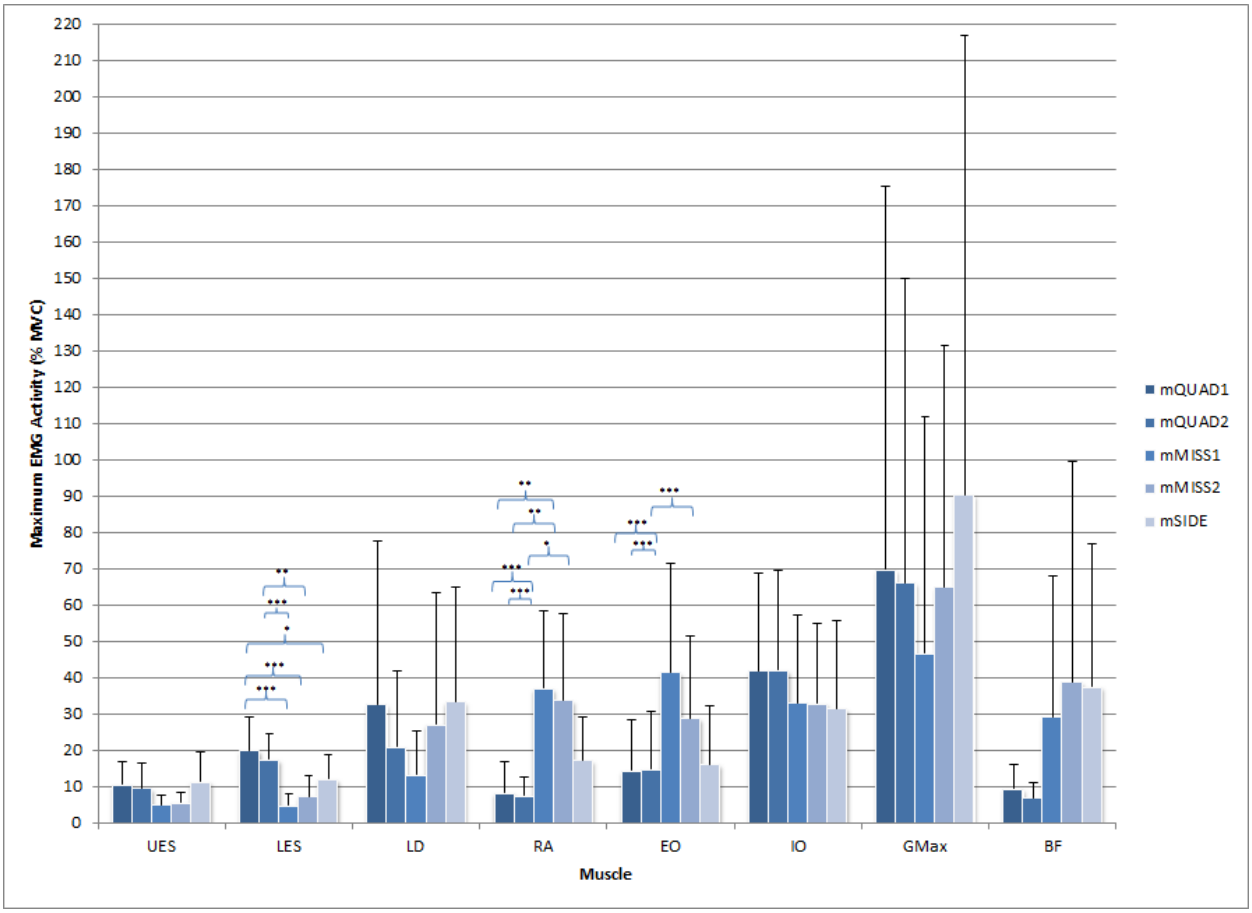


Fig. 27. Maximum % MVC achieved of all muscles across all coital positions for male subjects. Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$. The vertical error bars represent one standard deviation of the average peak EMG activity achieved for each muscle and coital positions.

4.1.2.2 Female

A summary of female EMG results discussed below can be found in Table 32, Table 33, Table 34, Table 35, and Table 36 in Appendix B.

4.1.2.2.1 Upper erector spinae

The maximum % MVC achieved during each coital position (Fig. 28) was highest for fSIDE (30.27 ± 19.59 % MVC), followed by both variations of fQUAD, fQUAD1 (15.68 ± 9.51 % MVC) and fQUAD2 (14.86 ± 17.55 % MVC), and both variations of fMISS, fMISS1 (12.63 ± 12.94 % MVC) and fMISS2 (11.29 ± 13.41 % MVC). No significant differences were found between positions (F=1.917, p=.139).

A similar trend to average maximum values above was seen for the % MVC values at amplitude probabilities of 0.1, 0.5, and 0.9. fSIDE (3.83 ± 3.53 % MVC, 7.70 ± 5.37 % MVC, and 16.31 ± 10.12 % MVC, respectively) had the highest values, followed by both variations of fQUAD, fQUAD2 (1.15 ± .76 % MVC, 2.31 ± 0.92 % MVC, and 6.28 ± 4.32 % MVC,

respectively) and fQUAD1 (1.48 ± .89 % MVC, 3.08 ± 2.21 % MVC, and 6.11 ± 4.48 % MVC, respectively), and both variations of fMISS, fMISS1 (2.74 ± 4.89 % MVC, 3.96 ± 7.56 % MVC, and 6.06 ± 9.79 % MVC, respectively) and fMISS2 (1.45 ± 1.05 % MVC, 3.35 ± 3.03 % MVC, and 5.30 ± 7.52 % MVC, respectively). Significant differences were found at amplitude probabilities of 0.5 (F=3.842, p=.017) and 0.9 (F=3.788, p=.016), but not 0.1 (F=2.183, p=.108). At an amplitude probability of 0.9, fSIDE was significantly different from fQUAD1 (p=.029), fQUAD2 (p=.039), and fMISS2 (p=.026). At an amplitude probability of 0.5, fSIDE was also significantly different from fQUAD2 (p=.018).

4.1.2.2.2 Lower erector spinae

A similar trend to UES results above was seen for the maximum % MVC of LES achieved during each coital position (Fig. 28). This value was highest for fSIDE (19.10 ± 12.28 % MVC), followed by both variations of fQUAD, fQUAD2 (11.58 ± 7.92 % MVC) and fQUAD1 (9.90 ± 5.18 % MVC), and both variations of fMISS, fMISS2 (9.55 ± 5.72 % MVC) and fMISS1 (2.89 ± 2.89 % MVC). fMISS1 was found to be significantly different from fSIDE (p=.001) (F=5.985, p=.001).

A similar trend to average maximum values above was seen for the % MVC values at amplitude probabilities of 0.1, 0.5, and 0.9. fSIDE (1.99 ± 3.04 % MVC, 4.74 ± 5.52 % MVC, and 10.31 ± 8.89 % MVC, respectively) had the highest values, followed by fQUAD2 (1.17 ± 1.06 % MVC, 2.13 ± 1.68 % MVC, and 6.43 ± 5.51 % MVC, respectively), fMISS2 (2.37 ± 3.81 % MVC, 2.96 ± 3.91 % MVC, and 5.99 ± 5.33 % MVC, respectively), fQUAD1 (1.01 ± 1.00 % MVC, 1.66 ± 1.23 % MVC, and 4.53 ± 2.10 % MVC), and fMISS1 (.55 ± .61 % MVC, 0.90 ± 0.91 % MVC, and 1.62 ± 1.50 % MVC, respectively). Significant differences between positions were not found at amplitude probabilities of 0.1 (F=.796, p=.540) and 0.5 (F=1.942, p=.135); however, fMISS1 was significantly different from fSIDE (p=.030) at an amplitude probability of 0.9 (F=3.770, p=.016).

4.1.2.2.3 Latissimus dorsi

The maximum % MVC achieved during each coital position (Fig. 28) was highest for fSIDE (30.39 ± 25.84 % MVC), followed by fQUAD1 (29.79 ± 42.69 % MVC), fMISS1 (23.66 ± 34.76% MVC), fQUAD2 (18.56 ± 14.31 % MVC), and fMISS2 (8.85 ± 4.72 % MVC). No significant differences were found between positions (F=1.085, p=.382).

The same trend as average maximum values above was seen for the % MVC values at amplitude probabilities of 0.1, 0.5, and 0.9. fSIDE (4.29 ± 2.35 % MVC, 8.93 ± 6.61 % MVC, and 16.46 ± 14.16 % MVC, respectively) had the highest values, followed by fQUAD1 (6.02 ± 5.70 % MVC, 10.00 ± 9.70 % MVC, and 16.12 ± 16.83 % MVC, respectively), fMISS1 (4.14 ± 6.66 % MVC, 7.80 ± 11.67 % MVC, and 12.78 ± 17.68 % MVC, respectively), fQUAD2 (3.57 ± 2.54 % MVC, 6.57 ± 4.41 % MVC, and 11.98 ± 10.07 % MVC, respectively), and fMISS2 (2.78 ± 3.05 % MVC, 3.91 ± 3.40 % MVC, and 5.69 ± 3.80 % MVC, respectively). No significant differences were found at amplitude probabilities of 0.1 (F=1.053, p=.397), 0.5 (F=1.280, p=.301), and 0.9 (F=1.407, p=.257).

4.1.2.2.4 Rectus abdominus

The maximum % MVC achieved during each coital position (Fig. 28) was highest for fMISS2 (12.22 ± 13.37 % MVC), followed by both variations of fQUAD, fQUAD2 (7.48 ± 6.91 % MVC) and fQUAD1 (6.86 ± 4.76 % MVC), fSIDE (6.80 ± 5.67 % MVC), and fMISS1 (4.18 ± 2.85 % MVC). All values were found to be fewer than 15% MVC. No significant differences were found between positions (F=1.237, p=.317).

A similar trend to average maximum values above was seen for the % MVC values at amplitude probabilities of 0.1, 0.5, and 0.9. fMISS2 (1.30 ± 1.38 % MVC, 2.57 ± 2.28 % MVC, and 7.49 ± 7.83 % MVC, respectively) had the highest % MVC values, followed by fSIDE (1.08 ± .76 % MVC, 1.90 ± 1.31 % MVC, and 3.85 ± 3.28 % MVC, respectively), both variations of fQUAD, fQUAD2 (.91 ± .83 % MVC, 1.49 ± 1.30 % MVC, and 3.04 ± 2.43 % MVC, respectively) and fQUAD1 (.99 ± .78 % MVC, 1.61 ± 1.18 % MVC, and 3.01 ± 2.32 % MVC, respectively), and fMISS1 (.83 ± 0.18 % MVC, 1.23 ± 0.59 % MVC, and 2.04 ± 1.01 % MVC, respectively) No significant differences were found at amplitude probabilities of 0.1 (F=.553, p=.698), 0.5 (F=1.634, p=.192), and 0.9 (F=2.815, p=.043).

4.1.2.2.5 External oblique

The maximum % MVC achieved during each coital position (Fig. 28) was highest for fSIDE (21.09 ± 15.88 % MVC), followed by both variations of fMISS, fMISS2 (11.07 ± 11.22 % MVC) and fMISS1 (10.61 ± 8.59 % MVC), and both variations of fQUAD, fQUAD1 (10.26 ± 9.77 % MVC) and fQUAD2 (7.81 ± 6.83 % MVC). All values, with the exception of fSIDE, were found to be fewer than 15 % MVC. fQUAD2 was found to be significantly different from fSIDE (p=.038) (F=2.271, p=.086).

A similar trend to average maximum values above was seen for the % MVC values at amplitude probabilities of 0.1, 0.5, and 0.9. fSIDE (2.36 ± 1.76 % MVC, 5.42 ± 3.76 % MVC, and 10.24 ± 6.79 % MVC, respectively) had the highest % MVC values, followed by fMISS2 (2.47 ± 1.83 % MVC, 3.63 ± 3.78 % MVC, and 7.36 ± 7.94 % MVC, respectively), fQUAD1 (2.47 ± 2.35 % MVC, 3.57 ± 3.88 % MVC, and 6.08 ± 6.12 % MVC), fMISS1 (2.73 ± 3.11 % MVC, 3.76 ± 3.90 % MVC, and 5.59 ± 4.87 % MVC), and fQUAD2 (1.67 ± 1.01 % MVC, 2.36 ± 1.54 % MVC, and 4.24 ± 3.18 % MVC, respectively). No significant differences were found at amplitude probabilities of 0.1 (F=.355, p=.838), 0.5 (F=1.232, p=.319), and 0.9 (F=1.758, p=.164).

4.1.2.2.6 Internal oblique

The maximum % MVC achieved during each coital position (Fig. 28) was highest for both variations of fMISS, fMISS2 (30.44 ± 26.18 % MVC) and fMISS1 (28.42 ± 33.35 % MVC), followed by fSIDE (20.09 ± 14.26% MVC), and both variations of fQUAD, fQUAD2 (14.58 ± 12.06 % MVC) and fQUAD1 (14.21 ± 14.69% MVC). No significant differences were found between positions (F=1.710, p=.176).

The same trend as average maximum values above was seen for the % MVC values at amplitude probabilities of 0.1, 0.5, and 0.9. Both variations of fMISS, fMISS2 (4.83 ± 4.08 % MVC, 7.64 ± 5.64 % MVC, and 16.93 ± 15.06 % MVC, respectively) and fMISS1 (4.11 ± 3.80 % MVC, 7.45 ± 7.95 % MVC, and 14.26 ± 15.55 % MVC, respectively), followed by fSIDE (2.57 ± 2.45 % MVC, 5.62 ± 5.16 % MVC, and 10.40 ± 8.47 % MVC), and both variations of fQUAD, fQUAD2 (3.08 ± 2.92 % MVC, 5.21 ± 4.70 % MVC, and 8.40 ± 7.38 % MVC, respectively) and fQUAD1 (2.43 ± 2.01 % MVC, 3.81 ± 3.02 % MVC, and 6.87 ± 6.52 % MVC, respectively). Significant differences were found at amplitude probabilities of 0.5 (F=2.061, p=.113) and 0.9 (F=2.108, p=.106) between fQUAD1 and fMISS2 (p=.038 and p=.036, respectively), but not 0.1 (F=1.758, p=.165).

4.1.2.2.7 Gluteus maximus

The maximum % MVC achieved during each coital position (Fig. 28) was highest for fMISS2 (34.49 ± 41.92 % MVC), followed by fQUAD1 (22.50 ± 29.79 % MVC), fMISS1 (20.11 ± 22.00 % MVC), fSIDE (12.46 ± 16.07 % MVC), and fQUAD2 (10.07 ± 9.88 % MVC). No significant differences were found between positions (F=2.180, p=.097).

At amplitude probabilities of 0.1, 0.5, and 0.9, both variations of fMISS, fMISS2 (4.33 ± 7.64 % MVC, 8.62 ± 14.98 % MVC, and 19.92 ± 27.51 % MVC, respectively) and fMISS1 (6.25 ± 4.43 % MVC, 7.66 ± 9.29 % MVC, and 11.73 ± 14.25 % MVC, respectively), had the highest % MVC values, followed by fQUAD1 (1.74 ± 1.40 % MVC, 4.06 ± 4.59 % MVC, and 8.33 ± 10.40 % MVC, respectively), fSIDE (1.29 ± 1.27 % MVC, 2.33 ± 2.33 % MVC, and 5.51 ± 5.30 % MVC, respectively), and fQUAD2 (1.48 ± 1.02 % MVC, 2.73 ± 2.03 % MVC, and 5.38 ± 4.97 % MVC, respectively). No significant differences were found at amplitude probabilities of 0.1 (F=2.726, p=.052), 0.5 (F=1.794, p=.158), and 0.9 (F=2.416, p=.072).

4.1.2.2.8 Biceps femoris

The maximum % MVC achieved during each coital position (Fig. 28) was highest for both variations of fMISS, fMISS1 (11.55 ± 15.44 % MVC) and fMISS2 (7.04 ± 5.82 % MVC), followed by both variations of fQUAD, fQUAD1 (4.81 ± 5.64 % MVC) and fQUAD2 (3.12 ± 2.66 % MVC), and fSIDE (2.48 ± 2.15 % MVC). All values were found to be fewer than 15 % MVC. No significant differences were found between positions (F=1.778, p=.161).

The same trend as average maximum values above was seen for the % MVC values at amplitude probabilities of 0.1, 0.5, and 0.9. Both variations of fMISS, fMISS1 (1.90 ± 2.35 % MVC, 3.24 ± 4.11 % MVC, and 9.08 ± 8.52 % MVC, respectively) and fMISS2 (2.31 ± 4.35 % MVC, 2.73 ± 4.40 % MVC, and 4.47 ± 4.90 % MVC, respectively), followed by both variations of fQUAD, fQUAD1 (.34 ± .37 % MVC, 0.94 ± .84 % MVC, and 2.45 ± 2.68 % MVC, respectively) and fQUAD2 (.54 ± .75 % MVC, 0.99 ± 1.20 % MVC, and 1.83 ± 1.80 % MVC, respectively), and fSIDE (.48 ± .62 % MVC, .71 ± 0.92 % MVC, and 1.21 ± 1.33 % MVC). Significant differences were found at amplitude probabilities of 0.1 (F=2.634, p=.066) and 0.9 (F=2.844, p=.043), but not 0.5 (F=1.470, p=.239). At an amplitude probability of 0.1, fMISS2 was found to be significantly different form fQUAD1 (p=.002), fQUAD2 (p=.006), and fSIDE

(p=.006). At an amplitude probability of 0.9, fMISS1 was also found to be significantly difference from fQUAD1 (p=.042), fQUAD2 (p=.022), and fSIDE (p=.013).

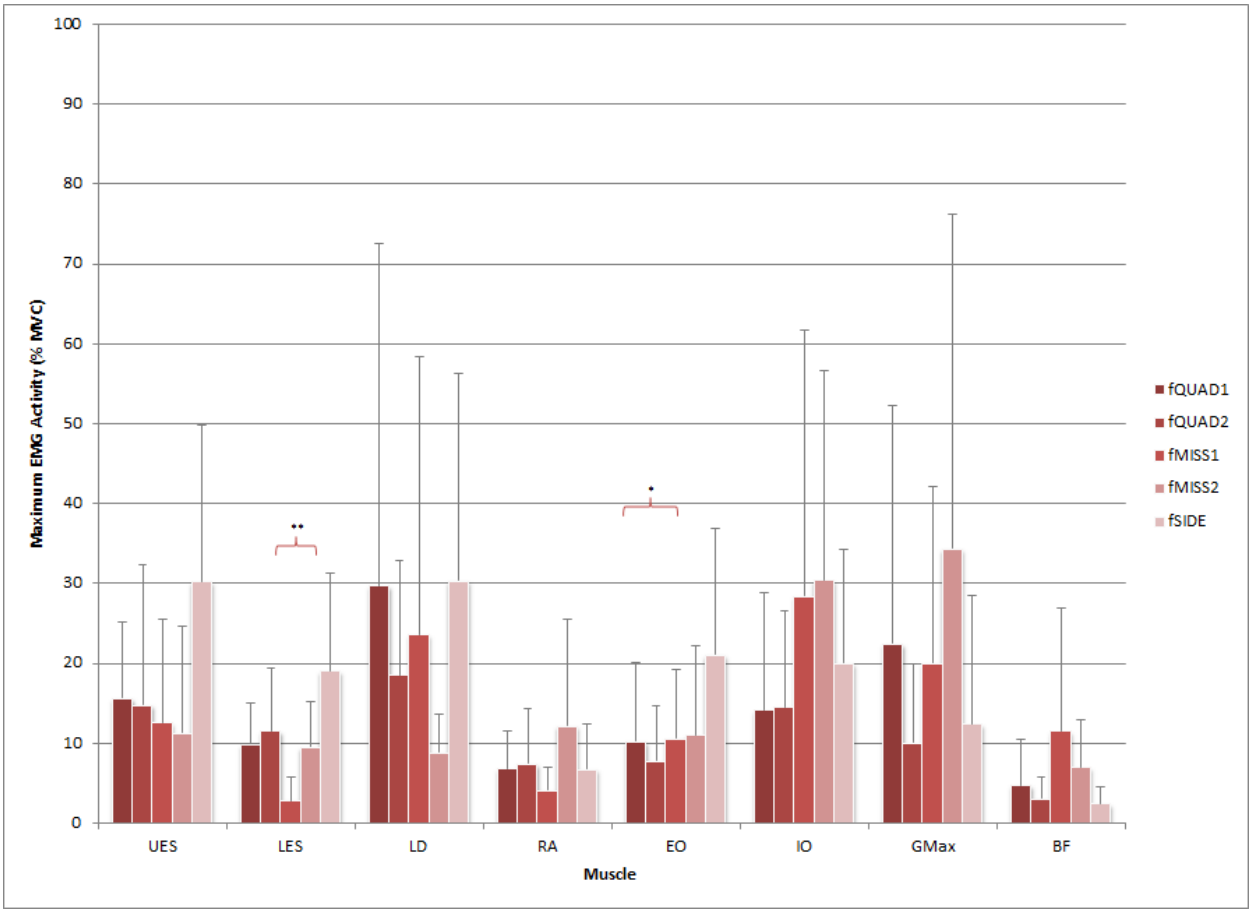


Fig. 28. Maximum % MVC achieved of all muscles across all coital positions for female subjects. Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$. The vertical error bars represent one standard deviation of the average peak EMG activity achieved for each muscle and coital positions.

4.2 Simulated versus real

A secondary objective of this study was to determine if simulated versions of each coital position were comparable to their 'real' counterparts. To determine this, a series of paired-sample t-tests were performed on each outcome variable of interest discussed above.

Table 5 and Table 6 summarize the outcome variables found to be statistically significant for male and female spine and hip kinematics and muscle activation patterns between real and simulated conditions. The significant results summarized in these tables are described below.

Table 5. Summary table of all male and female spine and hip kinematic outcome variables found to be significantly different between real and simulated conditions.

Sex	Position	Avg max	Avg min	APDF @ 0.1	APDF @ 0.5	APDF @ 0.9	Avg amplitude diff
Lumbar Spine							
Male	mQUAD1						
	mQUAD2			x*	x*	x*	
	mMISS1						
	mMISS2						
	mSIDE			x*	x*		
Female	fQUAD1						
	fQUAD2						
	fMISS1	x**	x**	x**	x***	x**	
	fMISS2		x*	x*	x**	x*	
	fSIDE		x*	x*	x*		
Hip							
Male	mQUAD1						
	mQUAD2						
	mMISS1	x*			x*	x*	
	mMISS2						
	mSIDE		x***	x***	x**		
Female	fQUAD1						
	fQUAD2						
	fMISS1	x*		x*	x*	x**	
	fMISS2						
	fSIDE	x**	x*	x*	x**	x***	

The 'x's indicate outcome variables where statistical significance was found between the simulated and real conditions. Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$. Note no significant differences were found for QUADRUPED1 for both males and females, fQUAD2, and the average amplitude difference outcome variable.

Table 6. Summary table of all male and female muscle activation outcome variables found to be significantly different between real and simulated conditions.

Sex	Position	UES	LES	LD	RA	EO	IO	GMax	BF
Peak EMG									
Male	mQUAD1								
	mQUAD2								
	mMISS1								
	mMISS2					x*	x*		
	mSIDE				x*				
Female	fQUAD1	x*							
	fQUAD2								
	fMISS1								
	fMISS2								
	fSIDE								
APDF @ 0.1									
Male	mQUAD1								
	mQUAD2								
	mMISS1	x**	x**		x*				
	mMISS2	x*	x*				x*		
	mSIDE								
Female	fQUAD1	x*				x*		x**	
	fQUAD2			x*					
	fMISS1				x**				
	fMISS2								
	fSIDE			x**	x*				
APDF @ 0.5									
Male	mQUAD1					x*			
	mQUAD2					x*			
	mMISS1	x**	x*					x*	
	mMISS2	x*	x*			x*	x*	x*	
	mSIDE								
Female	fQUAD1	x*							
	fQUAD2								
	fMISS1				x*				
	fMISS2								
	fSIDE			x*					
APDF @ 0.9									
Male	mQUAD1					x*	x*		
	mQUAD2								
	mMISS1	x*						x*	
	mMISS2	x*	x*			x*	x*		
	mSIDE								
Female	fQUAD1	x*							
	fQUAD2			x*	x*				
	fMISS1				x*				
	fMISS2								
	fSIDE								

The 'x's indicate outcome variables where statistical significance was found between the simulated and real conditions. Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$. Note no significant differences were found for fMISS2, LD and BF for males and LES, IO, BF for females.

4.2.1 Male

The number of penetration cycles per second in the real versions of QUADRUPED1 (1.80 ± .72 cycles/s; t=2.741, p=.023), MISSIONARY2 (1.34 ± .49 cycles/s; t=2.603, p=.029), and SIDELYING (1.50 ± .60 cycles/s; t=2.733, p=.023) were significantly faster than their simulated versions (1.44 ± .64 cycles/s, 1.02 ± .27 cycles/s, and 1.10 ± .47 cycles/s, respectively).

4.2.1.1 Lumbar spine

For mQUAD2 (Fig. 29), percentages of lumbar spine aROM achieved at amplitude probabilities of 0.1 (t=-2.570, p=.030), 0.5 (t=-2.510, p=.033), and 0.9 (t=-2.346, p=.044) were significantly different from the simulated version. Simulated mQUAD2 (-10.22 ± 25.53 % aROM, 2.27 ± 26.00 % aROM, 17.70 ± 31.91 % aROM) achieved less flexion than real mQUAD2 (-24.95 ± 15.60 % aROM, -12.54 ± 21.02 % aROM, and -.78 ± 27.15 % aROM).

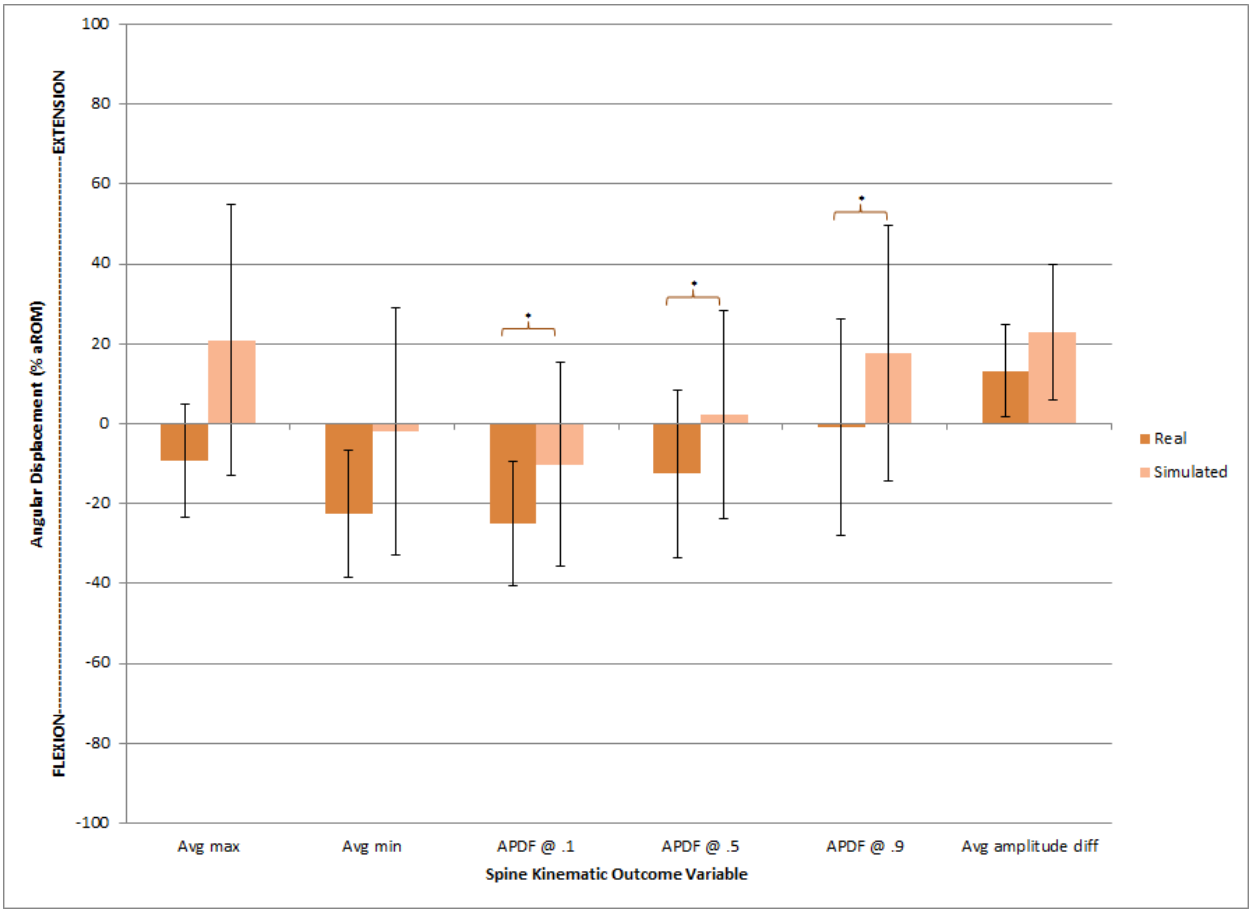


Fig. 29. Real and simulated mQUAD2 comparison results for male spine kinematic outcome variables. Simulated and real mQUAD2 varied across all amplitude probability levels. Statistical significance is represented by the following: $^{*}p$<.05, $^{**}p$<.01, $^{***}p$<.001. The vertical error bars represent one standard deviation of the average angular displacement values for each outcome variable.

For mSIDE (Fig. 30), percentages of lumbar spine aROM achieved at amplitude probabilities of 0.1 (-65.40 ± 15.37 % aROM; t=-2.357, p=.043) and 0.5 (-54.55 ± 16.55 % aROM; t=-2.352, p=.043) were significantly greater in flexion than the simulated version (-58.30 ± 19.80 % aROM and -46.29 ± 20.43 % aROM, respectively).

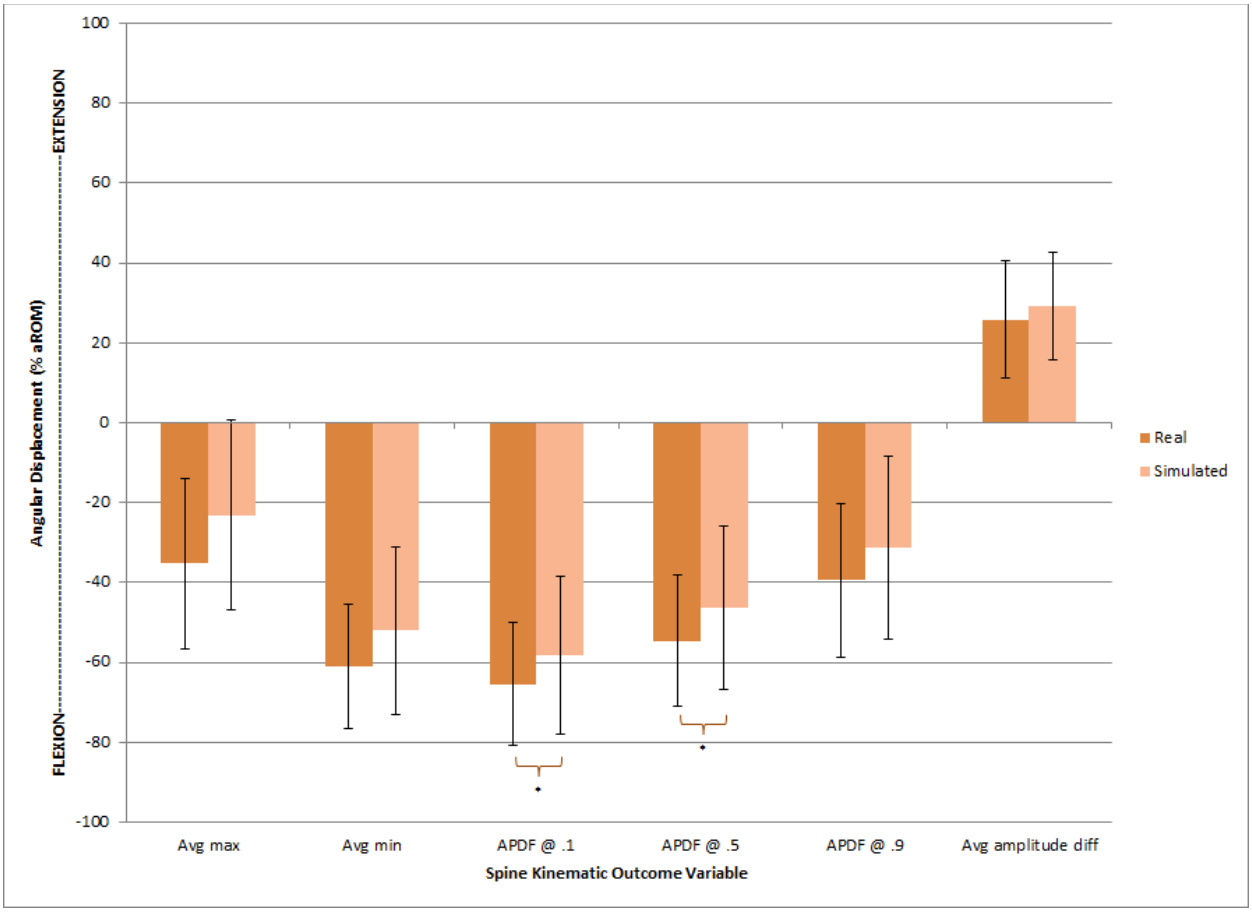


Fig. 30. Real and simulated mSIDE comparison results for male spine kinematic outcome variables. Statistical significance is represented by the following: $^{*}p$<.05, $^{**}p$<.01, $^{***}p$<.001. The vertical error bars represent one standard deviation of the average angular displacement values for each outcome variable.

4.2.1.2 Hip

For real mMISS1 (Fig. 31), the average maximum (56.38 ± 36.13 % aROM; t=3.196, p=.013) percentage of hip aROM achieved was significantly greater in extension than the simulated version (25.98 ± 35.81 % aROM) as well as percentages of hip aROM achieved at amplitude probabilities of 0.5 (23.28 ± 33.54 % aROM for real and -3.74 ± 23.57 % aROM for simulated; t=2.506, p=.037) and 0.9 (58.65 ± 37.12 % aROM for real and 28.99 ± 37.30 % aROM for simulated; t=2.800, p=.023). The average amplitude difference across all penetration cycles was trending towards significance (t=2.233, p=.056) with the value from real mMISS1 (67.03 ± 21.16 % aROM) being greater than simulated mMISS1 (50.12 ± 22.31 % aROM).

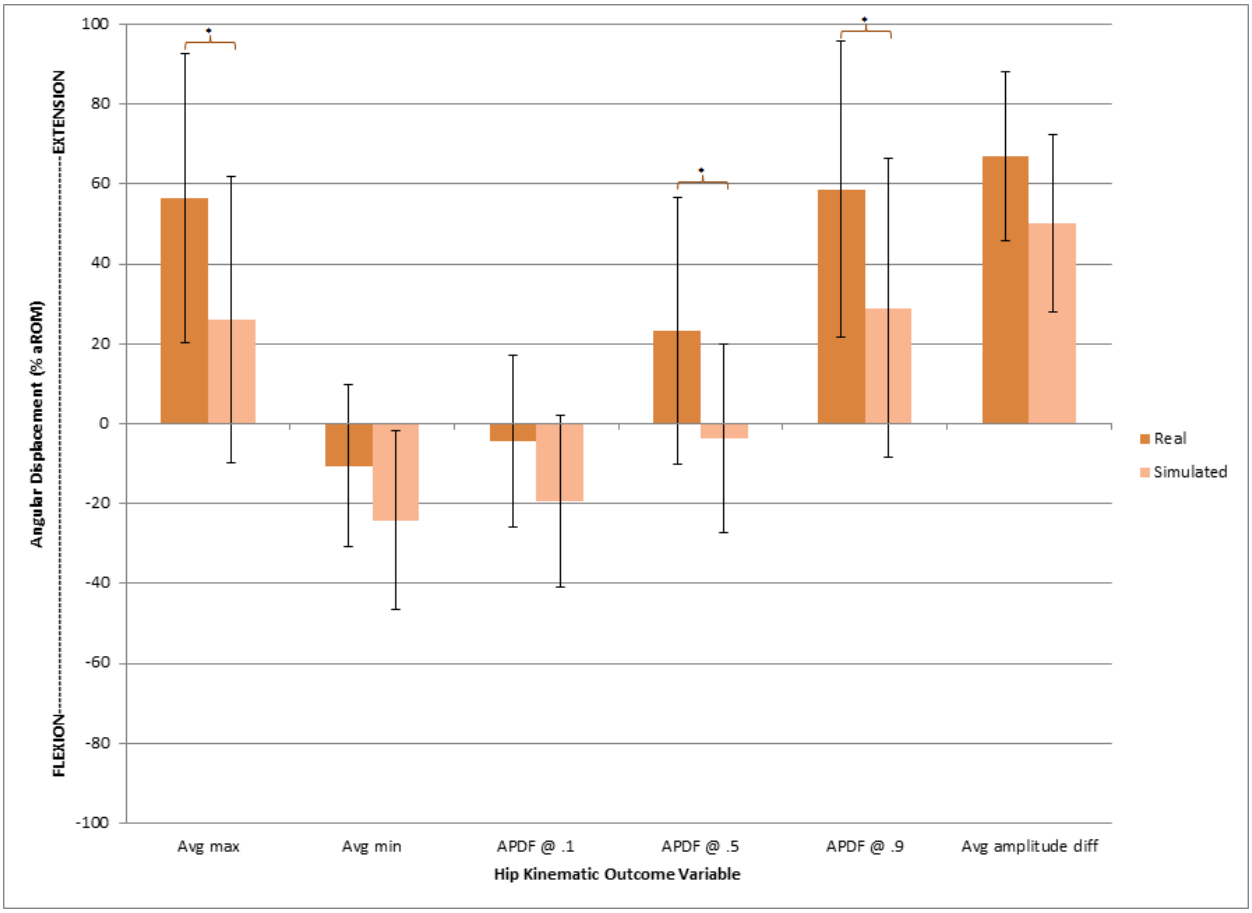


Fig. 31. Real and simulated mMISS1 comparison results for male hip kinematic outcome variables. Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$. The vertical error bars represent one standard deviation of the average angular displacement values for each outcome variable.

For mSIDE (Fig. 32), the average minimum (-31.38 ± 10.15 % aROM; t=7.057, p<.001) percentage of hip aROM achieved was significantly less flexion than the simulated version (-44.57 ± 12.83 % aROM) as well as percentages of hip aROM achieved at amplitude probabilities of 0.1 (-26.23 ± 9.93 % aROM for real and -38.81 ± 12.38 % aROM for simulated; t=6.303, p <.001) and 0.5 (-10.97 ± 11.11 % aROM for real and -23.38 ± 12.30 % aROM for simulated; t=3.387, p=.008).

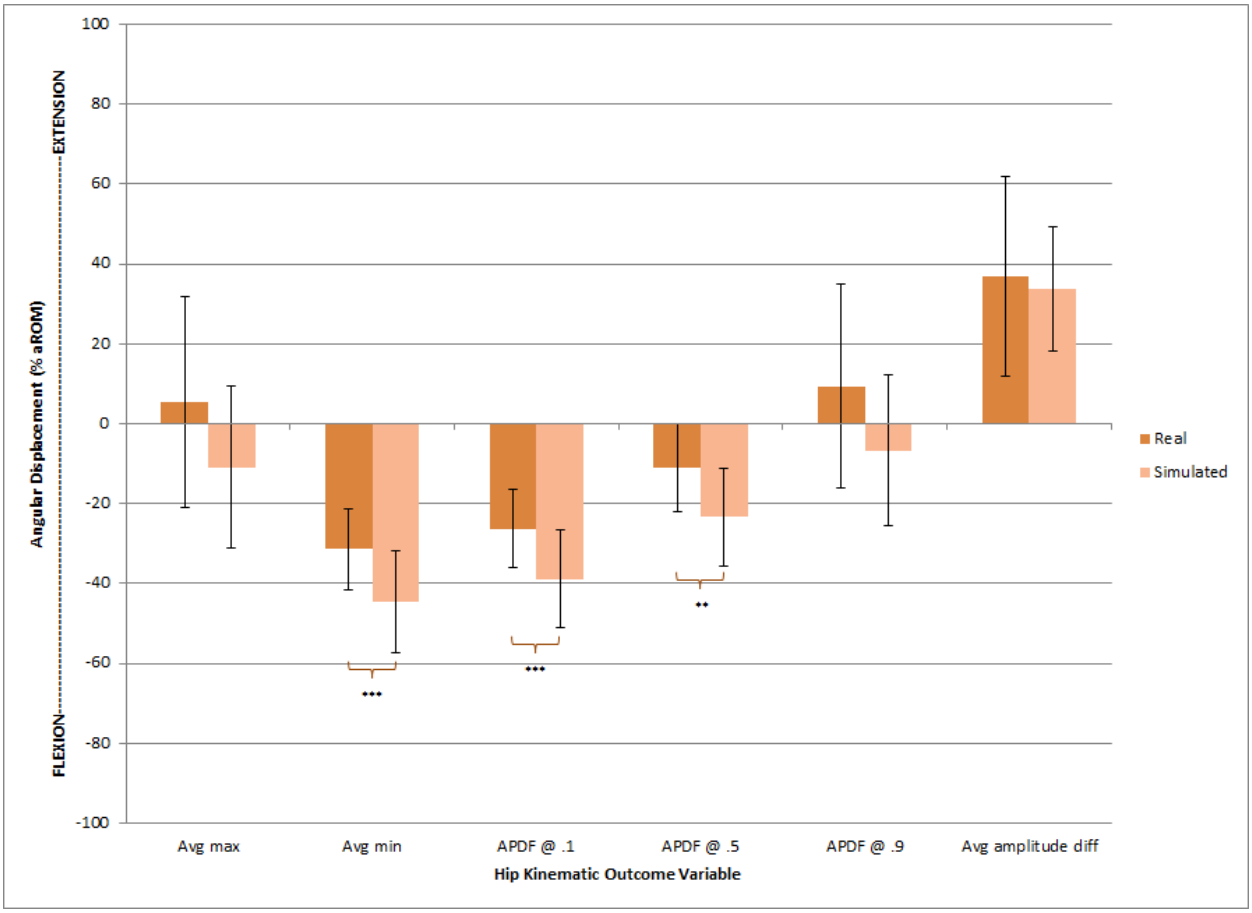


Fig. 32. Real and simulated mSIDE comparison results for male hip kinematic outcome variables. Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$. The vertical error bars represent one standard deviation of the average angular displacement values for each outcome variable.

4.2.1.3 Electromyography

For mQUAD1 (Fig. 33 and Fig. 34), the % MVC of EO values achieved during real mQUAD1 at amplitude probabilities of 0.5 (6.03 ± 7.58 % MVC; t=2.711, p=.027) and 0.9 (9.03 ± 10.19 % MVC; t=2.397, p=.043) were significantly greater than simulated mQUAD1 (4.44 ± 6.40 % MVC and 7.39 ± 11.16 % MVC, respectively) as well as % MVC of IO values at an amplitude probability of 0.9 (27.48 ± 20.38 % MVC for real and 13.21 ± 7.03 % MVC for simulated; t=2.317, p=.049).

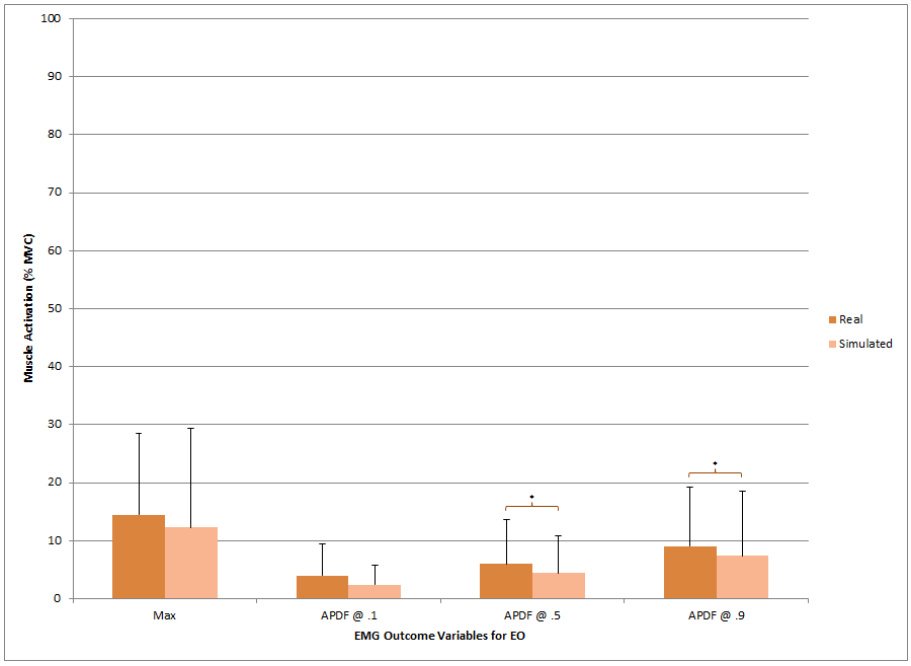


Fig. 33. Real and simulated mQUAD1 comparison results for male EO electromyography outcome variables.
Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$. The vertical error bars represent one standard deviation of the average muscle activity for each outcome variable.

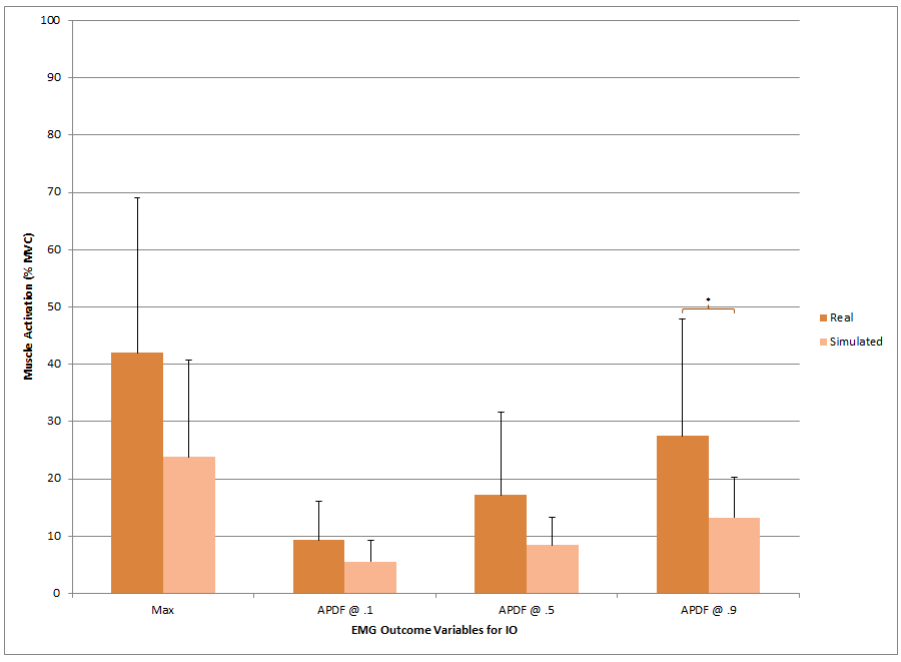


Fig. 34. Real and simulated mQUAD1 comparison results for male IO electromyography outcome variables.
Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$. The vertical error bars represent one standard deviation of the average muscle activity for each outcome variable.

For mQUAD2 (Fig. 35), the % MVC of EO values achieved during the real (6.03 ± 8.63 % MVC) and simulated (4.89 ± 8.02 % MVC) versions of mQUAD2 at an amplitude probability of 0.5 (t=2.576, p=.030) were significantly different, with the simulated version being less.

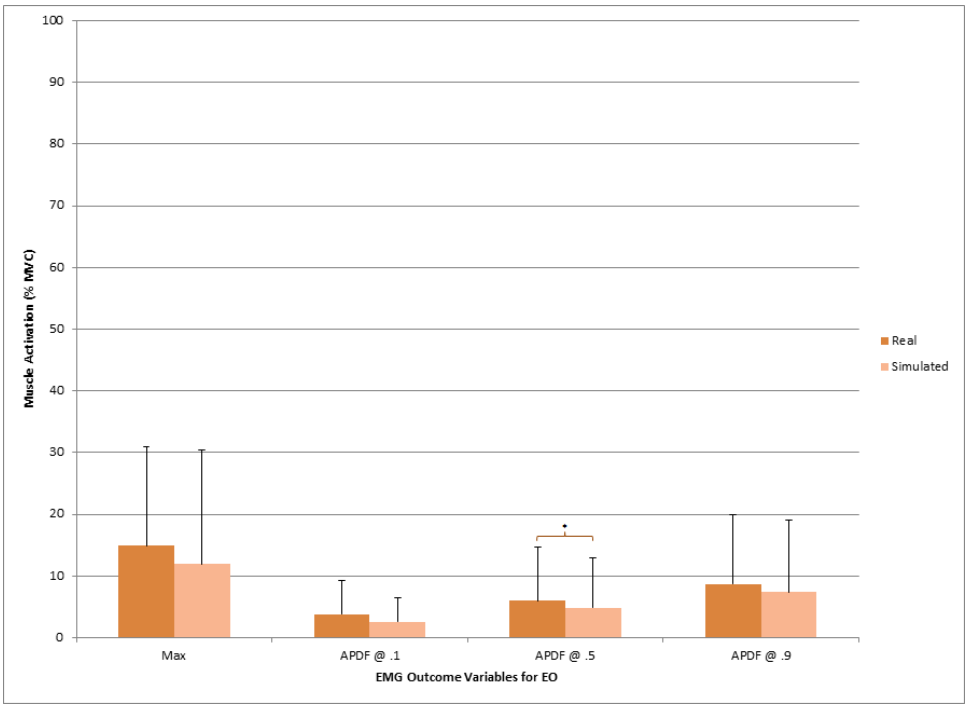


Fig. 35. Real and simulated mQUAD2 comparison results for male EO electromyography outcome variables.
Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$. The vertical error bars represent one standard deviation of the average muscle activity for each outcome variable.

For mMISS1 (Fig. 36, Fig. 37, Fig. 38, and Fig. 39), the % MVC of UES values achieved during the real (.91 ± 0.58 % MVC, 1.67 ± .82 % MVC, and 2.97 ± 1.39 % MVC, respectively) and simulated (.53 ± .36 % MVC, 0.98 ± .71 % MVC, and 1.59 ± 1.18 % MVC, respectively) versions of mMISS1 at amplitude probabilities of 0.1 (t=4.721, p=.003), 0.5 (t=4.606, p=.002), and 0.9 (t=2.832, p=.025) were significantly different as well as % MVC of LES values at amplitude probabilities of 0.1 (.59 ± 0.54 % MVC for real and .36 ± .32 % MVC for simulated; t=3.593, p=.009) and 0.5 (1.15 ± 0.97 % MVC for real and .65 ± .47 % MVC for simulated; t=2.427, p=.046), % MVC of RA values at an amplitude probability of 0.1 (6.28 ± 4.32 % MVC for real and 2.92 ± 2.49 % MVC for simulated; t=2.657, p=.033), and % MVC of IO values at amplitude probabilities of 0.5 (10.53 ± 7.52 % MVC for real and 4.37 ± 2.74 % MVC for simulated; t=2.893, p=.023) and 0.9 (18.60 ± 13.13 % MVC for real and 8.17 ± 3.90 % MVC for simulated; t=2.939, p=.022). Essentially, the back muscles and most of the abdominal muscles had smaller values during the simulated version of mMISS1.

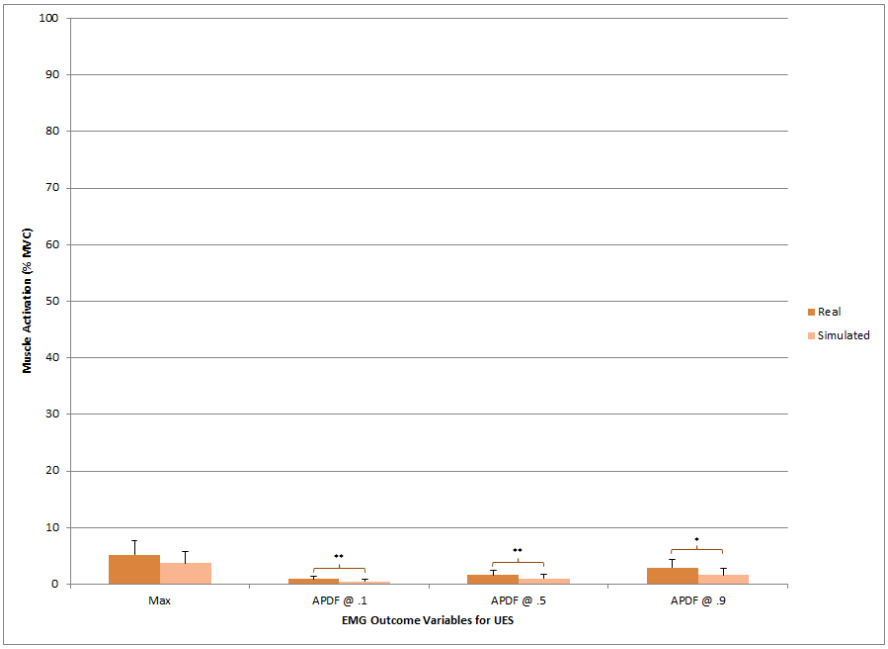


Fig. 36. Real and simulated mMISS1 comparison results for male UES electromyography outcome variables.
Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$. The vertical error bars represent one standard deviation of the average muscle activity for each outcome variable.

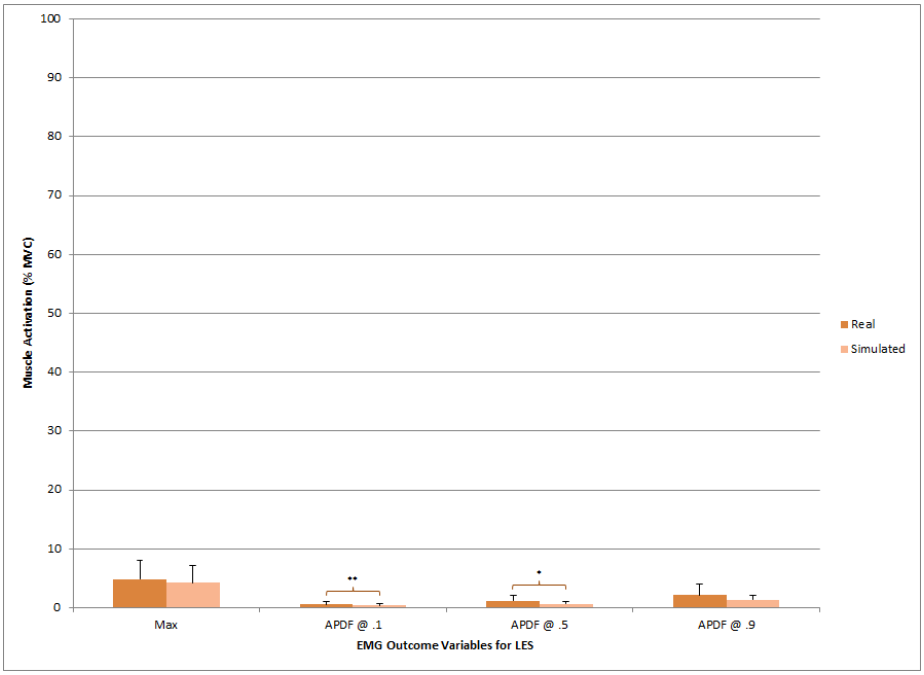


Fig. 37. Real and simulated mMISS1 comparison results for male LES electromyography outcome variables.
Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$. The vertical error bars represent one standard deviation of the average muscle activity for each outcome variable.

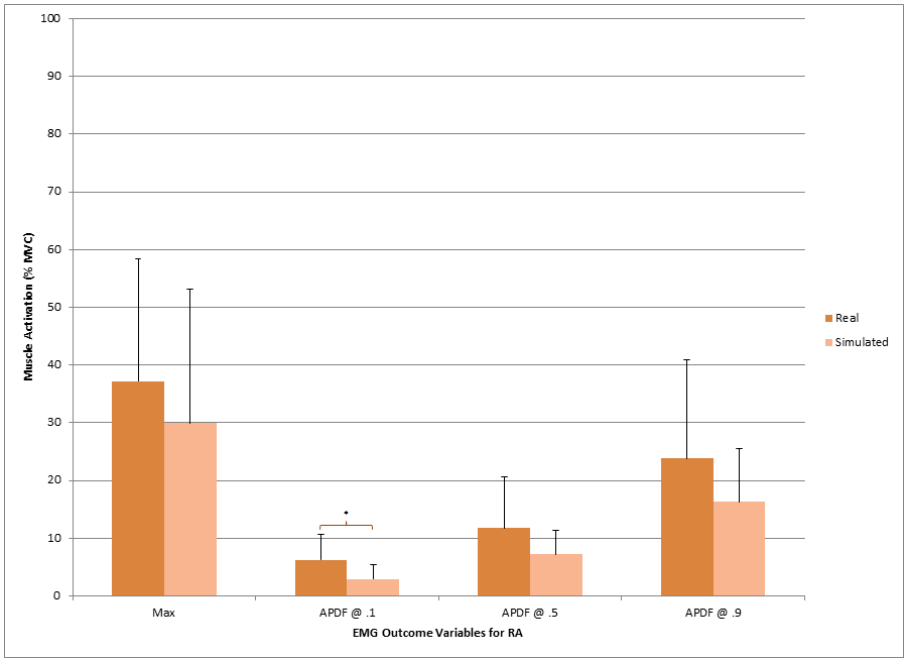


Fig. 38. Real and simulated mMISS1 comparison results for male RA electromyography outcome variables.
Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$. The vertical error bars represent one standard deviation of the average muscle activity for each outcome variable.

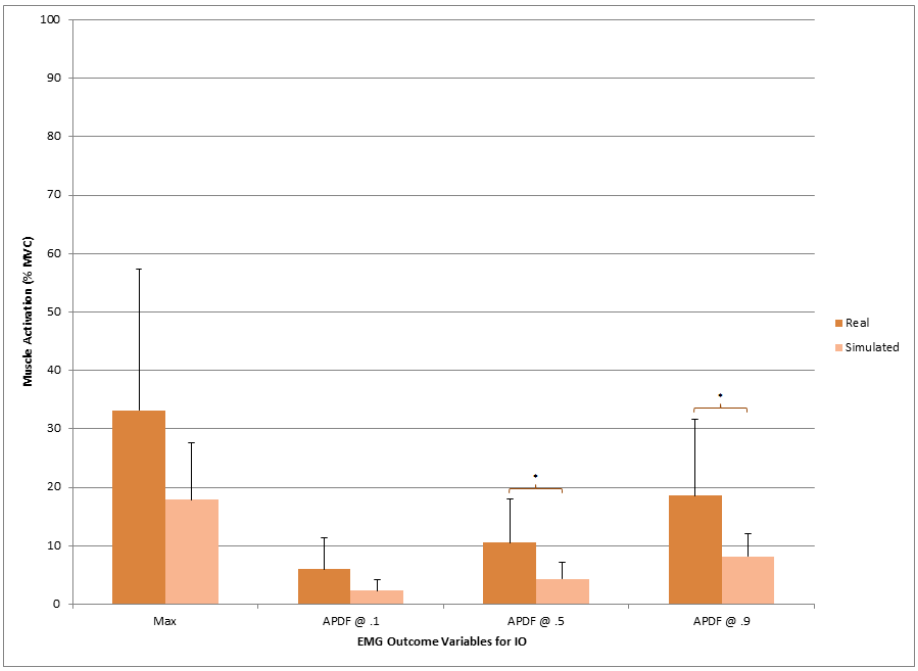


Fig. 39. Real and simulated mMISS1 comparison results for male IO electromyography outcome variables.
Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$. The vertical error bars represent one standard deviation of the average muscle activity for each outcome variable.

For mMISS2 (Fig. 40, Fig. 41, Fig. 42, Fig. 43, and Fig. 44), the average maximum % MVC of EO and IO achieved during the real (29.02 ± 22.51 % MVC and 32.98 ± 22.11 % MVC, respectively) and simulated (17.50 ± 16.27 % MVC and 16.83 ± 10.08 % MVC, respectively) version of mMISS2 were significantly different (t=3.020, p=.017 and t=2.534, p=.035, respectively). Furthermore, the % MVC of UES values achieved during the real (1.02 ± .61 % MVC, 1.89 ± 0.95 % MVC, and 2.83 ± 1.89 % MVC, respectively) and simulated (.60 ± 0.52 % MVC, 1.02 ± .65 % MVC, and 1.76 ± .85 % MVC, respectively) versions of mMISS2 at amplitude probabilities of 0.1 (t=2.382, p=.049), 0.5 (t=2.925, p=.022), and 0.9 (t=2.594, p=.036) were significantly different as well as % MVC of LES values at amplitude probabilities of 0.1 (.55 ± .38 % MVC for real and .32 ± 0.19 % MVC for simulated; t=3.307, p=.016), 0.5 (1.09 ± .84 % MVC for real and 0.52 ± .35 % MVC for simulated; t=3.270, p=.011), and 0.9 (2.41 ± 2.04 % MVC and 1.13 ± .71 % MVC for simulated; t=2.321, p=.049), % MVC of EO values at amplitude probabilities of 0.5 (6.98 ± 7.07 % MVC for real and 3.25 ± 2.55 % MVC for simulated; t=2.346, p=.047) and 0.9 (16.07 ± 14.79 % MVC for real and 8.66 ± 8.29 % MVC for simulated; t=2.451, p=.040), % MVC of IO values at amplitude probabilities of 0.1 (2.86 ± 3.41 % MVC for real and 1.44 ± 1.50 % MVC for simulated; t=2.598, p=.036), 0.5 (7.74 ± 6.53 % MVC for real and 2.97 ± 2.24 % MVC for simulated; t=3.379, p=.010) and 0.9 (16.51 ± 10.70 % MVC for real and 7.45 ± 4.72 % MVC for simulated; t=3.097, p=.015), and % MVC of GMax values at an amplitude probability of 0.5 (3.95 ± 4.45 % MVC for real and 1.22 ± 2.66 % MVC for simulated; t=3.129, p=.017). Similar to mMISS1, the back muscles and most of the core muscles, as well as GMax had smaller values for the simulated version of mMISS2.

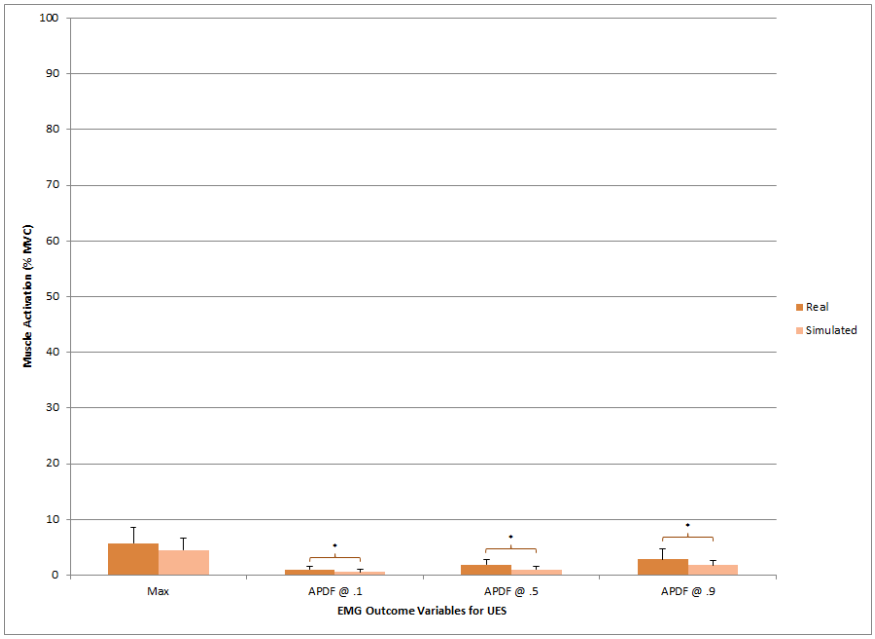


Fig. 40. Real and simulated mMISS2 comparison results for male UES electromyography outcome variables.
Statistical significance is represented by the following: $^{*}p$<.05, $^{**}p$<.01, $^{***}p$<.001. The vertical error bars represent one standard deviation of the average muscle activity for each outcome variable.

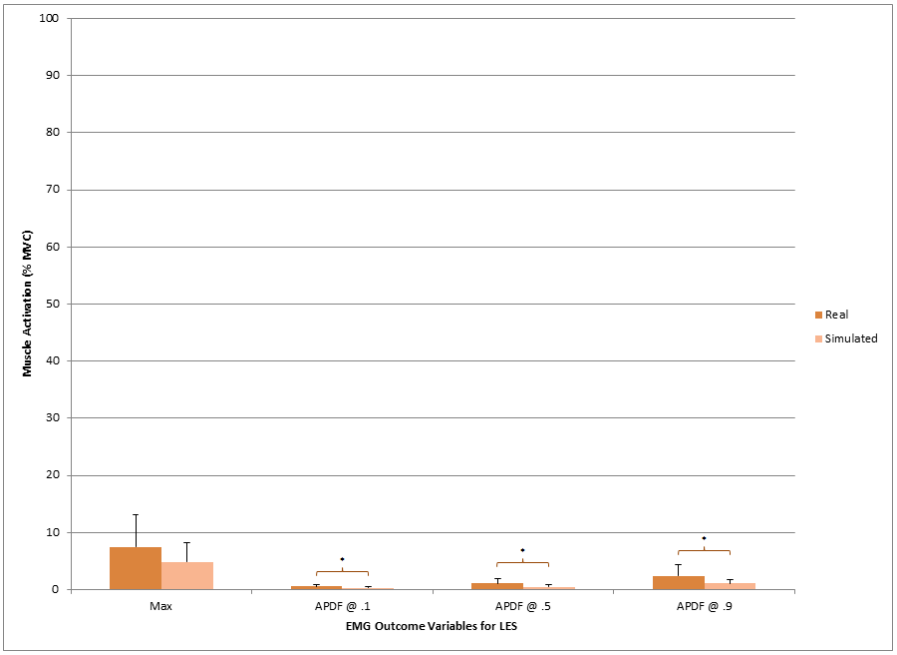


Fig. 41. Real and simulated mMISS2 comparison results for male LES electromyography outcome variables.
Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$. The vertical error bars represent one standard deviation of the average muscle activity for each outcome variable.

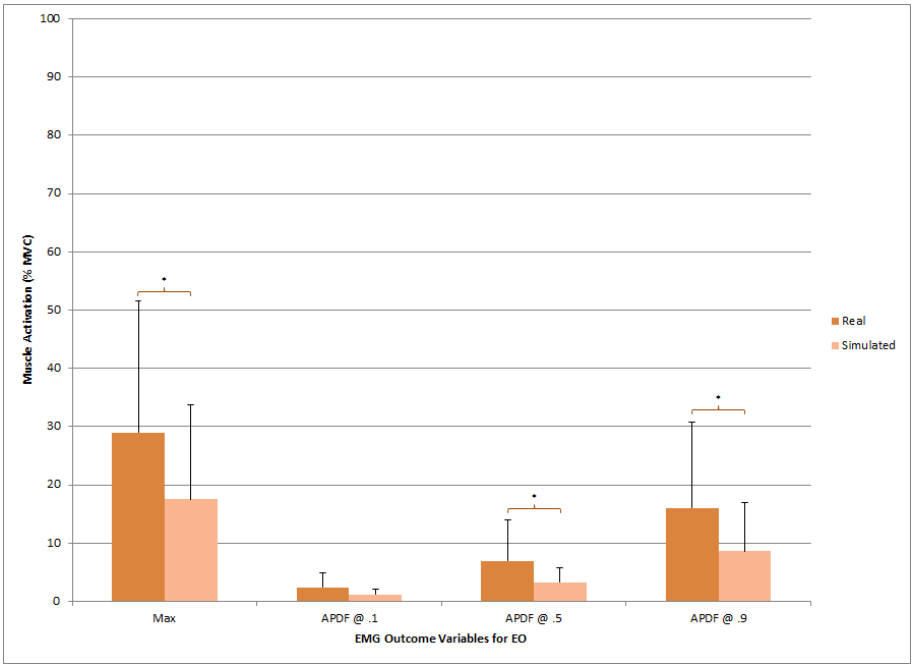


Fig. 42. Real and simulated mMISS2 comparison results for male EO electromyography outcome variables.
Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$. The vertical error bars represent one standard deviation of the average muscle activity for each outcome variable.

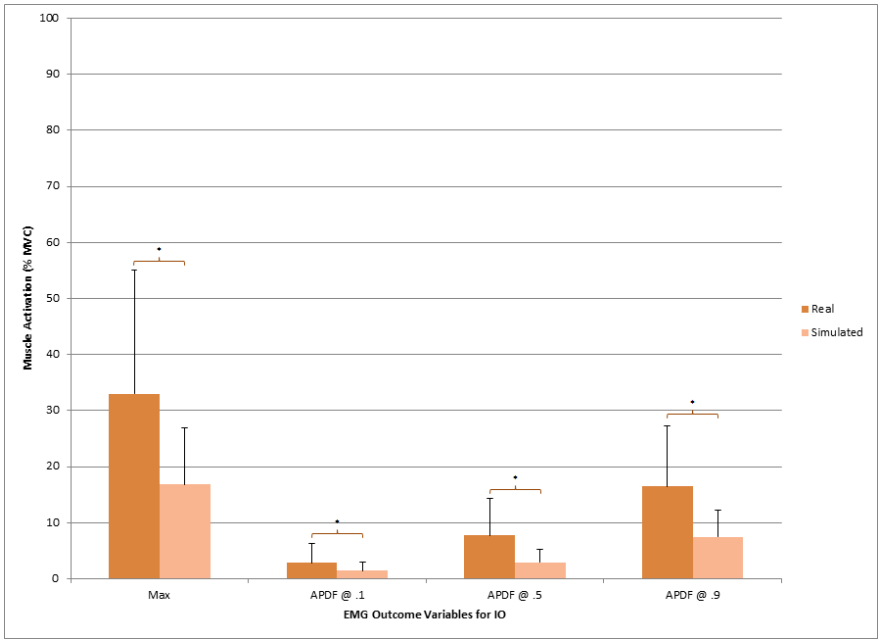


Fig. 43. Real and simulated mMISS2 comparison results for male IO electromyography outcome variables.
Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$. The vertical error bars represent one standard deviation of the average muscle activity for each outcome variable.

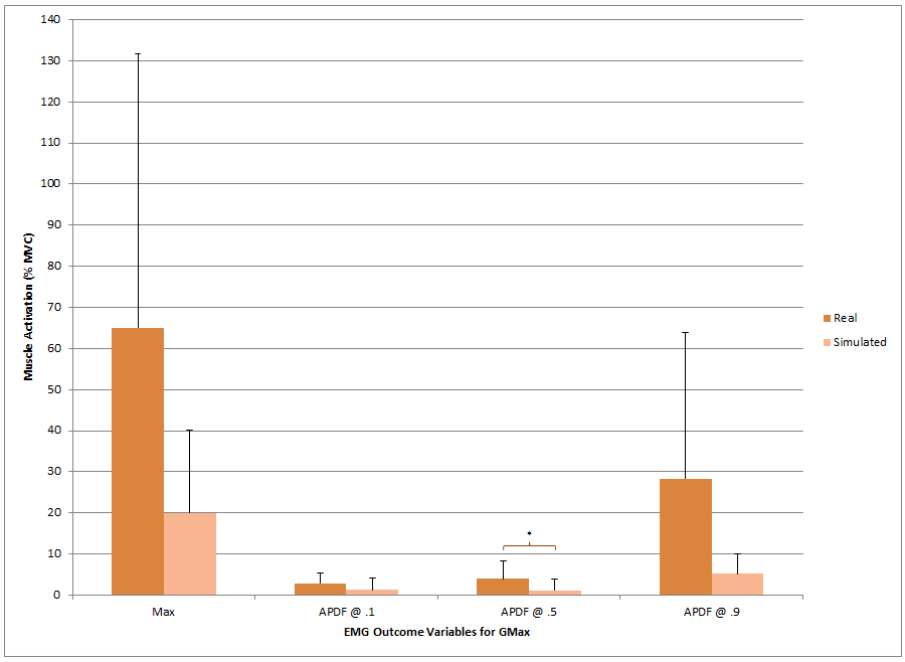


Fig. 44. Real and simulated mMISS2 comparison results for male GMax electromyography outcome variables.
Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$. The vertical error bars represent one standard deviation of the average muscle activity for each outcome variable.

For mSIDE (Fig. 45), the average maximum % MVC of RA achieved during the real (17.38 ± 11.91 % MVC) and simulated (11.55 ± 8.28 % MVC) version of mSIDE was significantly different (t=2.312, p=.046).

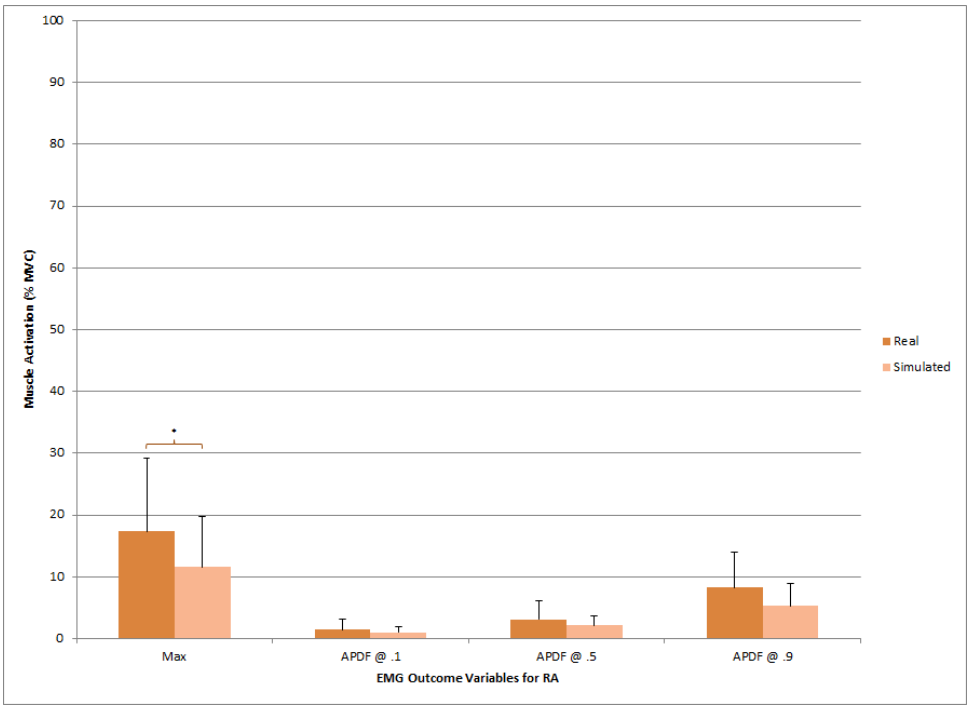


Fig. 45. Real and simulated mSIDE comparison results for male RA electromyography outcome variables.
Statistical significance is represented by the following: $^{*}p$<.05, $^{**}p$<.01, $^{***}p$<.001. The vertical error bars represent one standard deviation of the average muscle activity for each outcome variable.

4.2.2 Female

4.2.2.1 Lumbar spine

For fMISS1 (Fig. 46), the average maximum (t=-4.873, p=.005) and minimum (t=-7.584, p=.001) percentages of lumbar spine aROM achieved were significantly different from the simulated version, with the average maximum in extension aROM for simulated fMISS1 (10.76 ± 21.21 % aROM) and flexion aROM for real fMISS1 (-22.01 ± 17.78 % aROM). The average minimum for simulated fMISS1 (-14.31 ± 9.03 % aROM) was significantly less than real (-43.78 ± 14.57 % aROM). Furthermore, percentages of lumbar spine aROM achieved at amplitude probabilities of 0.1 (t=-6.501, p=.001), 0.5 (t=-8.053, p<.001), and 0.9 (t=-4.703, p=.005) were fluctuating through more extension aROM for simulated fMISS1 (-10.72 ± 8.44 % aROM, 1.33 ± 10.76 % aROM, and 16.02 ± 19.28 % aROM, respectively) than real (-40.16 ± 15.36 % aROM, -28.16 ± 13.04 % aROM, and -15.59 ± 15.92 % aROM, respectively).

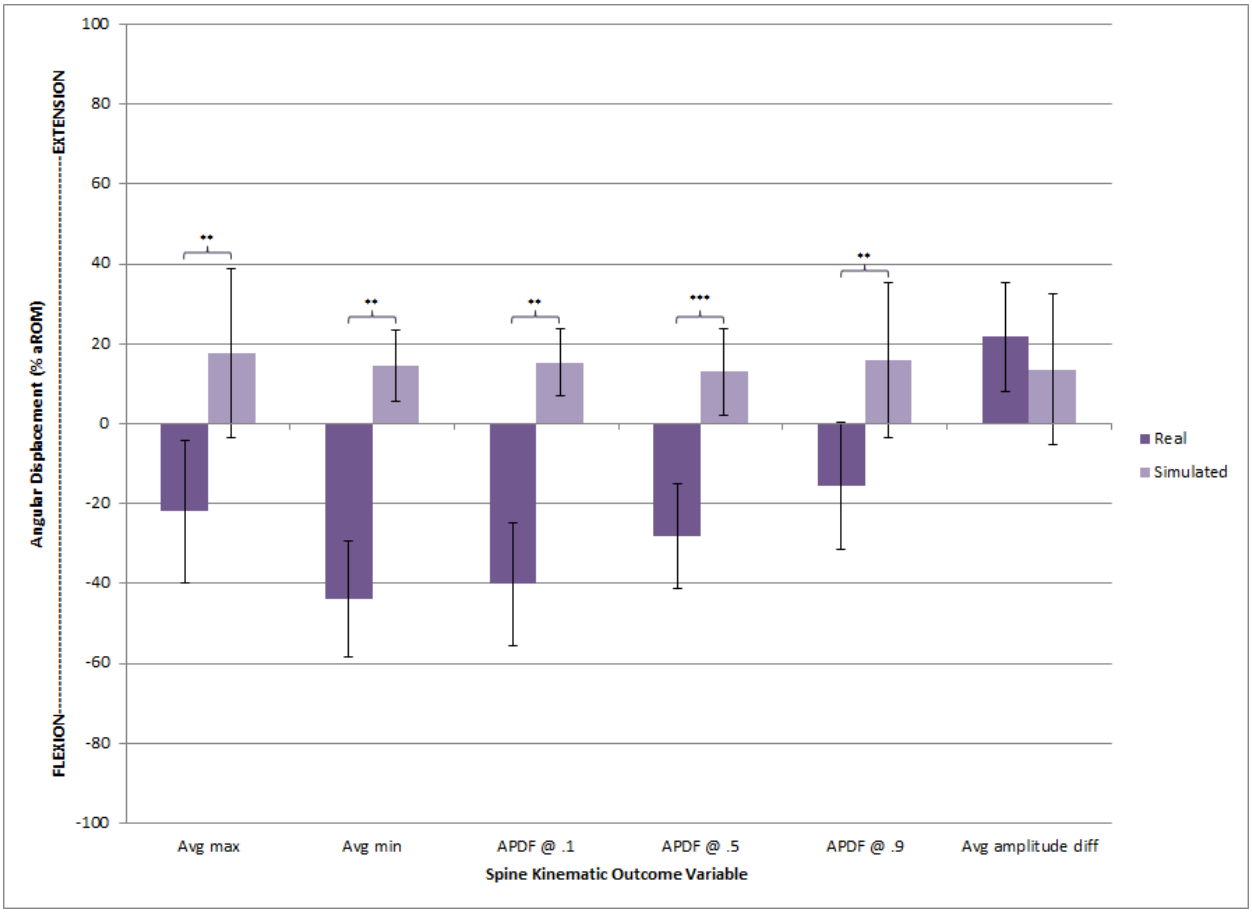


Fig. 46. Real and simulated fMISS1 comparison results for female spine kinematic outcome variables. Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$. The vertical error bars represent one standard deviation of the average angular displacement values for each outcome variable.

For fMISS2 (Fig. 47), the average minimum (t=-2.950, p=.018) percentage of lumbar spine aROM achieved was significantly greater in flexion aROM in the real (-62.34 ± 16.91 % aROM) than the simulated version (-54.60 ± 21.19 % aROM) as well as percentages of lumbar spine aROM achieved at amplitude probabilities of 0.1 (-58.29 ± 17.41 % aROM for real and -50.59 ± 2.76 % aROM for simulated; t=-3.019, p=.017), 0.5 (-50.70 ± 16.13 % aROM for real and -40.46 ± 18.67 % aROM for simulated; t=-3.422, p=.009), and 0.9 (-38.80 ± 13.70 % aROM for real and -27.85 ± 16.60 % aROM for simulated; t=-2.370, p=.045). The average maximum percentage of lumbar spine aROM was also trending towards significance (t=-2.196, p=.059), with less flexion % aROM achieved in simulated fMISS2 (-33.46 ± 16.33 % aROM) than real (-44.42 ± 14.47 % aROM).

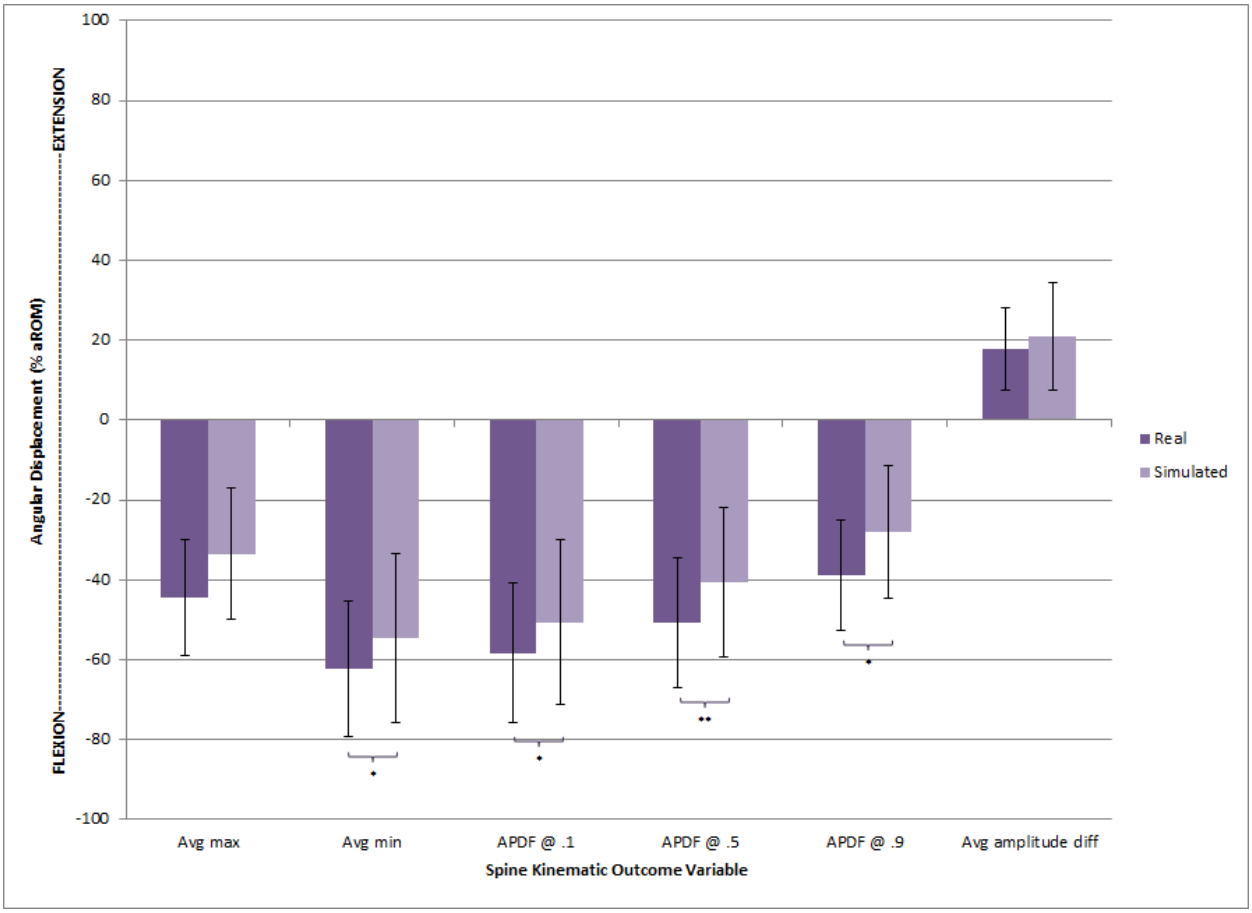


Fig. 47. Real and simulated fMISS2 comparison results for female spine kinematic outcome variables. Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$. The vertical error bars represent one standard deviation of the average angular displacement values for each outcome variable.

For fSIDE (Fig. 48), the average minimum (t=3.057, p=.018) percentage of lumbar spine aROM achieved was significantly different from the simulated version, with the average minimum values for simulated fSIDE in the flexion aROM (-8.77 ± 29.63 % aROM) and extension aROM for real fSIDE (12.09 ± 36.67 % aROM). Furthermore, percentages of lumbar spine aROM achieved at amplitude probabilities of 0.1 (t=3.244, p=.010) and 0.5 (t=2.886, p=.018) were significantly different (12.30 ± 34.38 % aROM and 26.65 ± 35.97 % aROM, respectively for real and -6.77 ± 25.39 % aROM and 7.27 ± 25.60 % aROM, respectively for simulated).

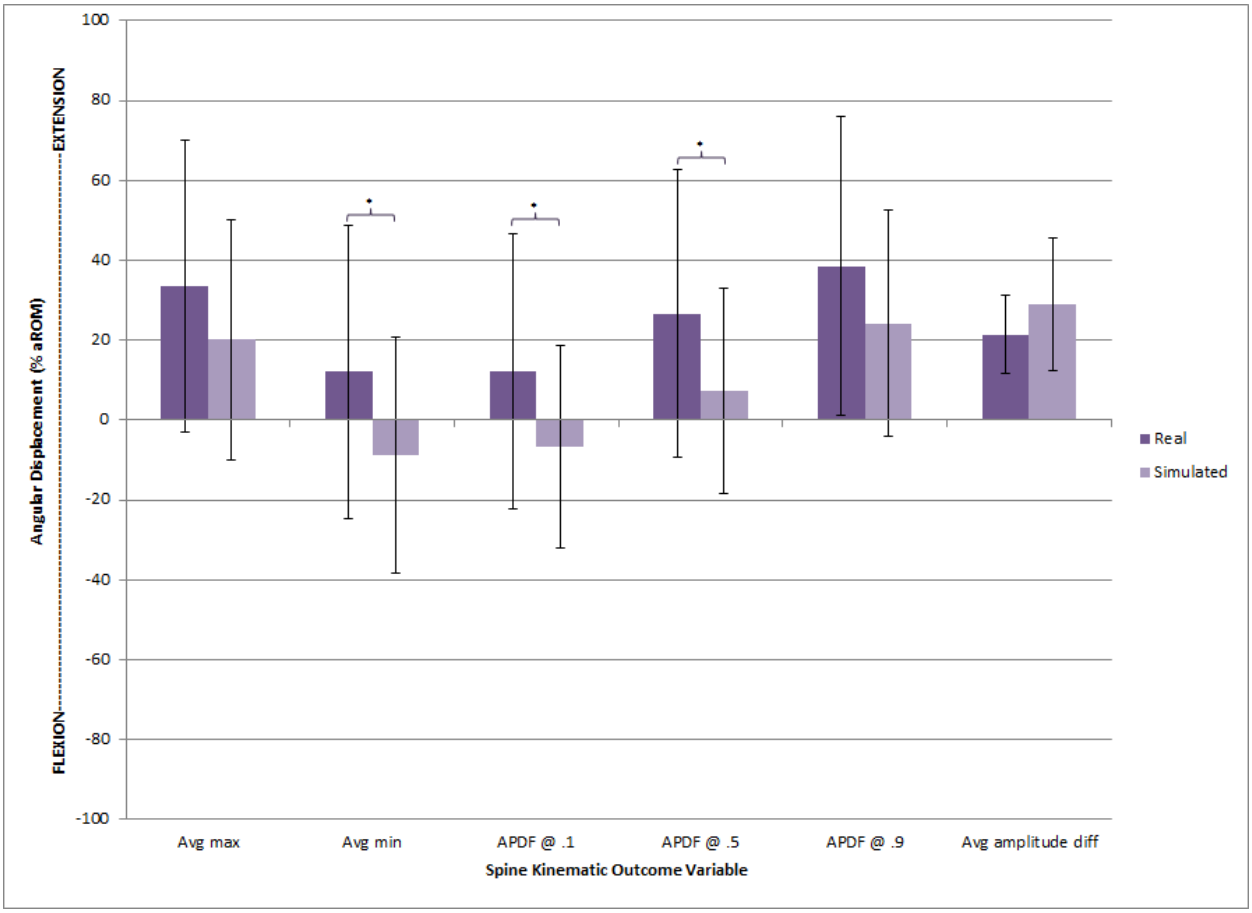


Fig. 48. Real and simulated fSIDE comparison results for female spine kinematic outcome variables. Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$. The vertical error bars represent one standard deviation of the average angular displacement values for each outcome variable.

4.2.2.2 Hip

For fMISS1 (Fig. 49), the average maximum (t=-4.434, p=.021) percentage of hip aROM achieved was significantly different from the simulated version, with the average maximum value for simulated fMISS1 in extension aROM (7.77 ± 24.29 % aROM) and flexion aROM for real fMISS1 (-4.27 ± 25.85 % aROM). Furthermore, percentages of hip aROM achieved at amplitude probabilities of 0.1 (t=-2.660, p=.045), 0.5 (t=-2.932, p=.033), and 0.9 (t=-4.189, p=.009) were significantly different – at all three amplitude probabilities, simulated fMISS1 was within hip extension aROM (4.72 ± 21.26 % aROM, 10.74 ± 23.58 % aROM, and 19.06 ± 25.84 % aROM, respectively) and real fMISS1 was not (-8.31 ± 19.18 % aROM, -1.44 ± 21.61 % aROM, and 8.46 ± 27.27 % aROM, respectively).

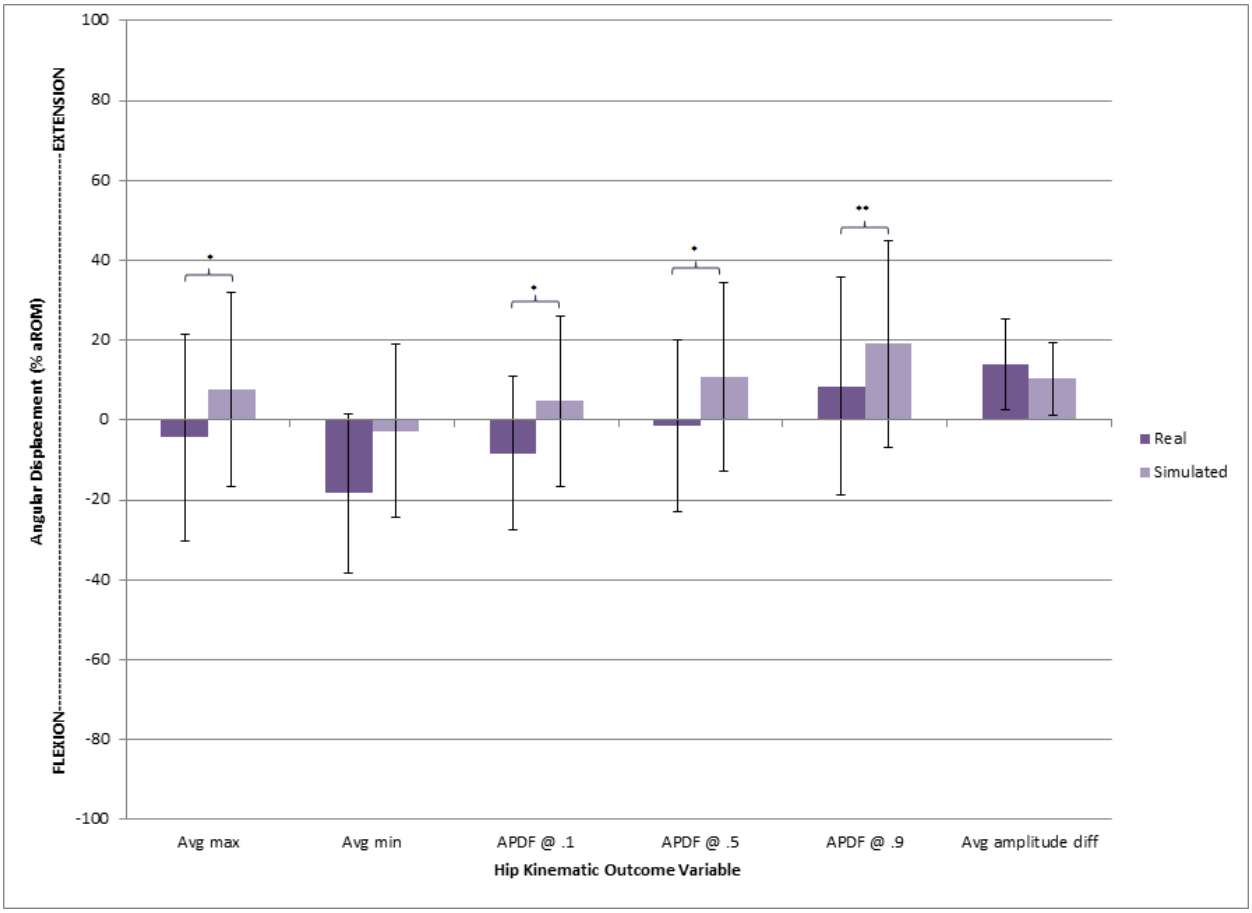


Fig. 49. Real and simulated fMISS1 comparison results for female hip kinematic outcome variables. Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$. The vertical error bars represent one standard deviation of the average angular displacement values for each outcome variable.

For fSIDE (Fig. 50), the average maximum (t=-5.580, p=.001) and minimum (t=-2.386, p=.044) percentages of hip aROM achieved were significantly greater in flexion for the real (-62.88 ± 16.88 % aROM and -69.43 ± 17.61 % aROM, respectively) than the simulated version (-47.60 ± 15.68 % aROM and -58.02 ± 15.55 % aROM, respectively) as well as percentages of hip aROM achieved at amplitude probabilities of 0.1 (-66.09 ± 17.66 % aROM for real and -57.04 ± 17.33 % aROM for simulated; t=-2.785, p=.021), 0.5 (-61.31 ± 17.38 % aROM for real and -50.85 ± 17.29 % aROM for simulated; t=-3.929, p=.003), and 0.9 (-56.20 ± 17.25 % aROM for real and -44.11 ± 17.37 % aROM for simulated; t=-5.433, p<.001).

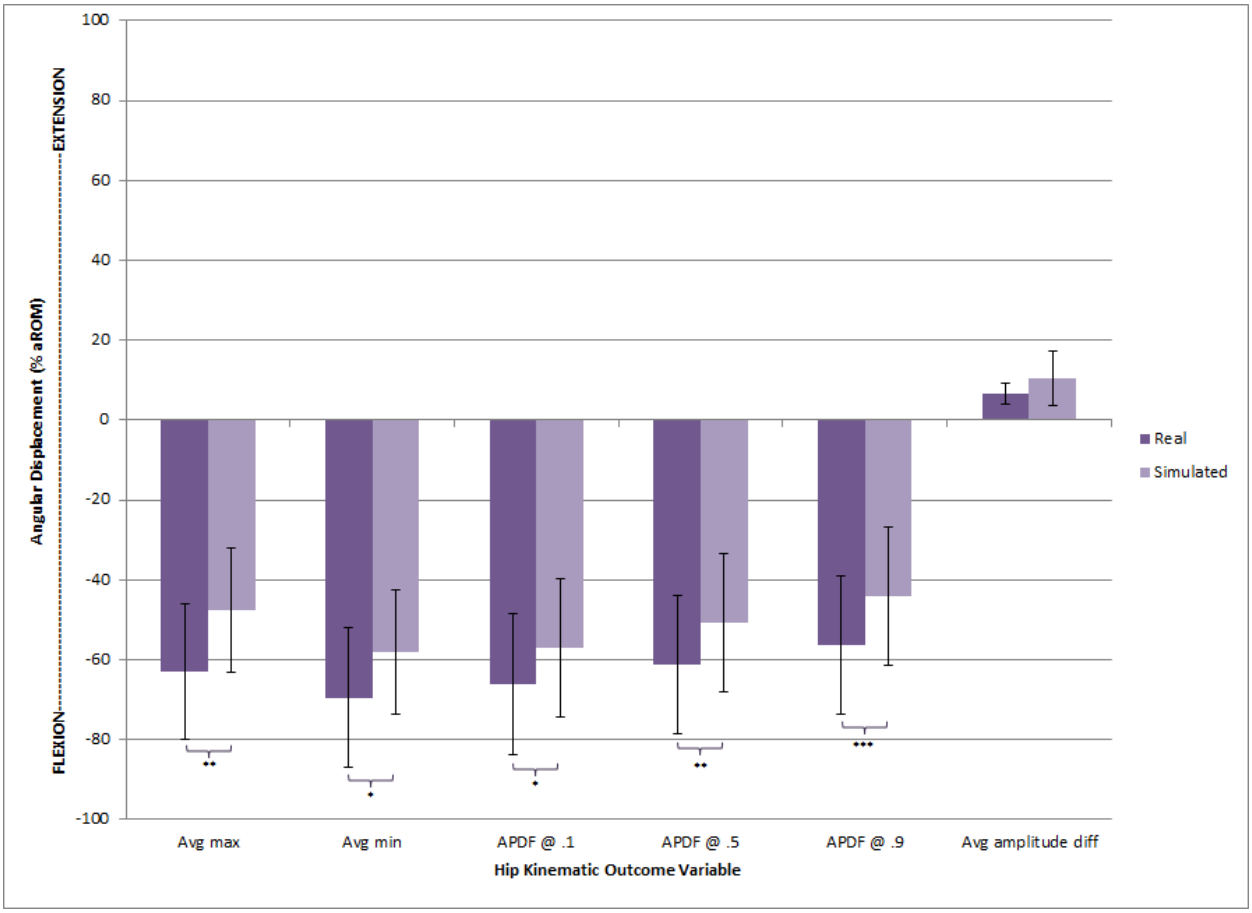


Fig. 50. Real and simulated fSIDE comparison results for female hip kinematic outcome variables. Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$. The vertical error bars represent one standard deviation of the average angular displacement values for each outcome variable.

4.2.2.3 Electromyography

For fQUAD1 (Fig. 51, Fig. 52, and Fig. 53), the average maximum % MVC of UES achieved during the real version of fQUAD1 (15.68 ± 9.51 % MVC) was significantly greater than the simulated version (7.25 ± 4.46 % MVC) (t=2.616, p=.031). Furthermore, the % MVC of UES, EO, and GMax values achieved during the real (1.48 ± .89 % MVC, 2.47 ±2.35 % MVC, and 1.74 ± 1.40 % MVC, respectively) and simulated (.57 ± .22 % MVC, 1.49 ± 1.43 % MVC, and 0.55 ± .46 % MVC, respectively) versions of fQUAD1 at an amplitude probability of 0.1 were significantly different (t=2.937, p=.022, t=2.535, p=.039, and t=3.561, p=.009, respectively). The % MVC of UES values for real (3.08 ± 2.21 % MVC and 6.11 ± 4.48 % MVC, respectively) and simulated (1.23 ± .35 % MVC and 2.40 ± 0.98 % MVC, respectively) conditions of fQUAD1 were also significantly different for amplitude probabilities of 0.5 (t=2.366, p=.050) and 0.9 (t=2.702, p=.027).

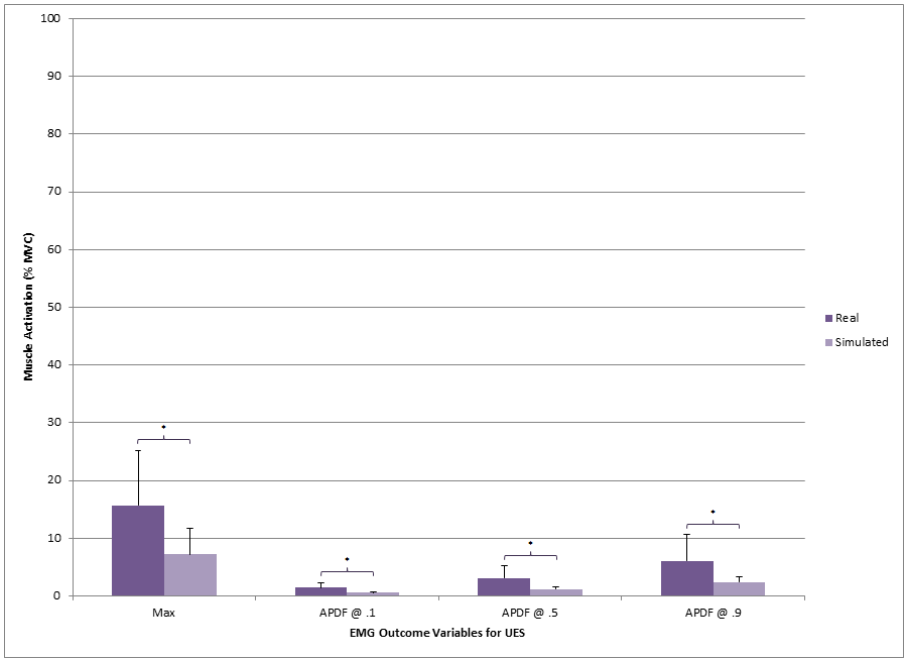


Fig. 51. Real and simulated fQUAD1 comparison results for female UES electromyography outcome variables.
Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$. The vertical error bars represent one standard deviation of the average muscle activity for each outcome variable.

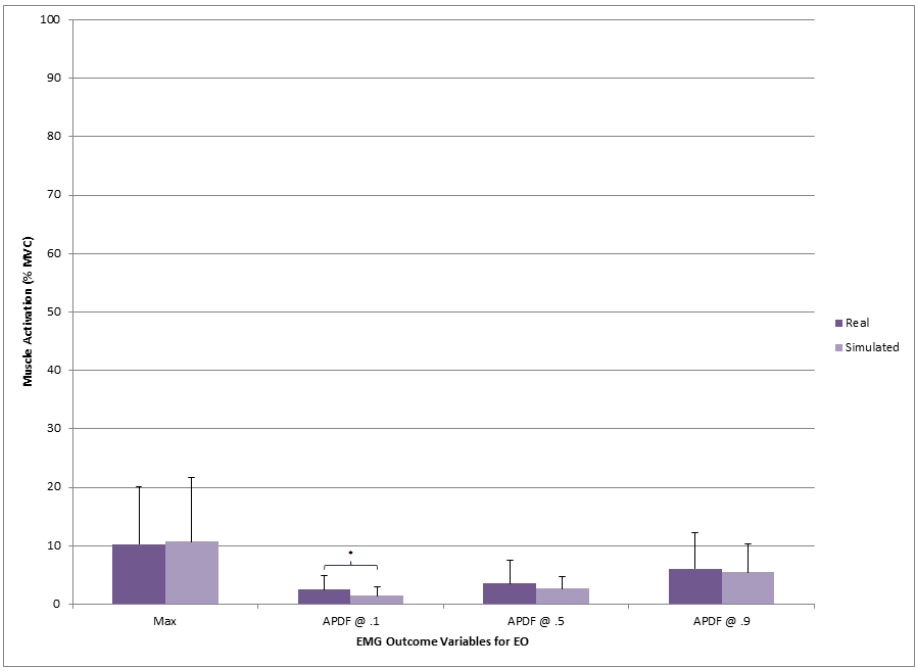


Fig. 52. Real and simulated fQUAD1 comparison results for female EO electromyography outcome variables.
Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$. The vertical error bars represent one standard deviation of the average muscle activity for each outcome variable.

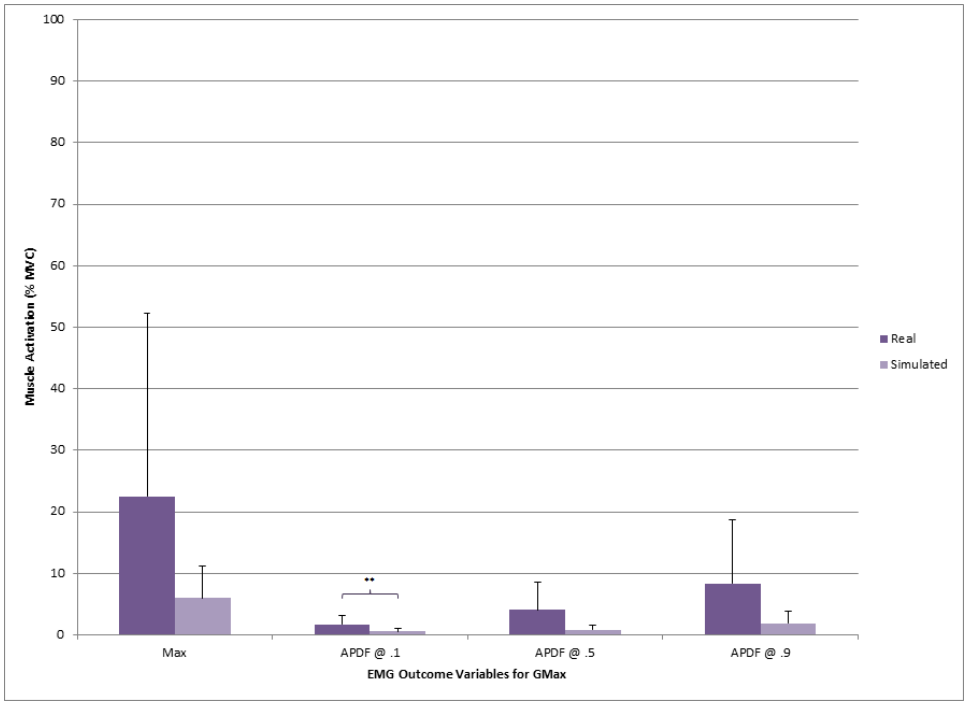


Fig. 53. Real and simulated fQUAD1 comparison results for female GMax electromyography outcome variables.

Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$. The vertical error bars represent one standard deviation of the average muscle activity for each outcome variable.

For fQUAD2 (Fig. 54 and Fig. 55), the % MVC of LD values achieved during the real (3.57 ± 2.54 % MVC and 11.98 ± 10.07 % MVC, respectively) and simulated (2.48 ± 1.46 % MVC and 8.86 ± 7.28 % MVC, respectively) versions of fQUAD2 at amplitude probabilities of 0.1 (t=2.443, p=.037) and 0.9 (t=2.264, p=.050) were significantly different, as well as % MVC of RA values at an amplitude probability of 0.9 (3.04 ± 2.43 % MVC for real and 2.29 ± 2.06 % MVC for simulated; t=2.409, p=.039).

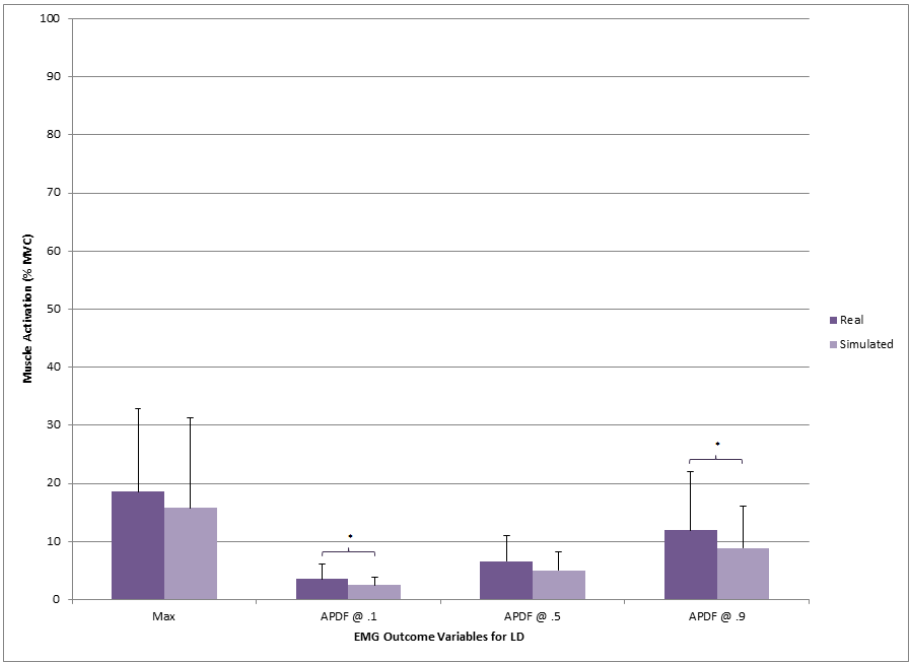


Fig. 54. Real and simulated fQUAD2 comparison results for female LD electromyography outcome variables.
Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$. The vertical error bars represent one standard deviation of the average muscle activity for each outcome variable.

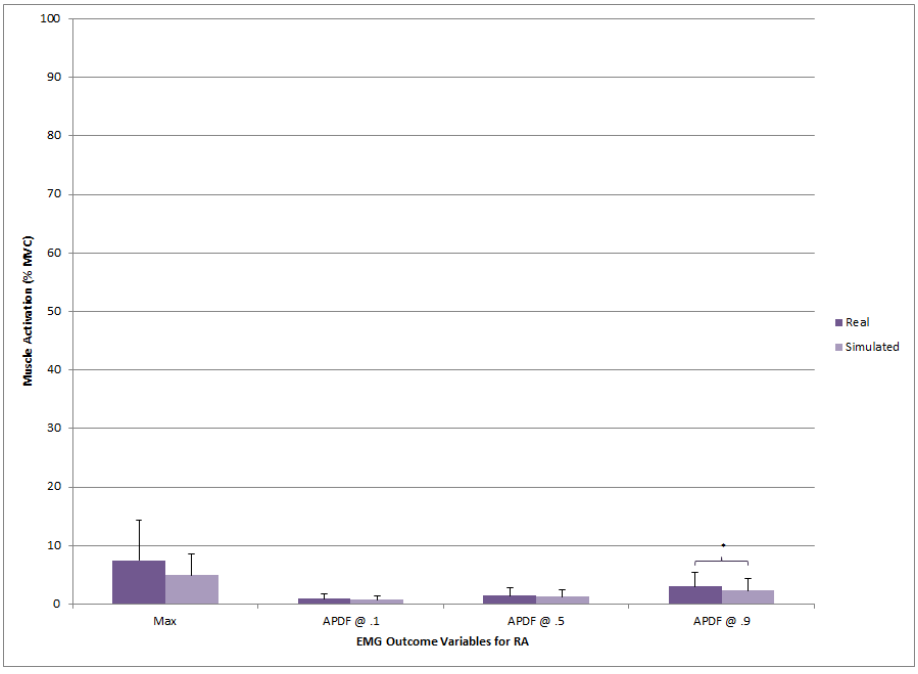


Fig. 55. Real and simulated fQUAD2 comparison results for female RA electromyography outcome variables.
Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$. The vertical error bars represent one standard deviation of the average muscle activity for each outcome variable.

For fMISS1 (Fig. 56), the % MVC of RA values achieved during the real (.83 ± 0.18 % MVC, 1.23 ± 0.59 % MVC, and 2.04 ± 1.01 % MVC, respectively) and simulated (.42 ± 0.14 % MVC, .69 ± .35 % MVC, and 1.19 ± 0.59 % MVC, respectively) versions of fMISS1 at amplitude probabilities of 0.1 (t=8.142, p=.004), 0.5 (t=3.557, p=.024), and 0.9 (t=3.043, p=.038) were significantly different.

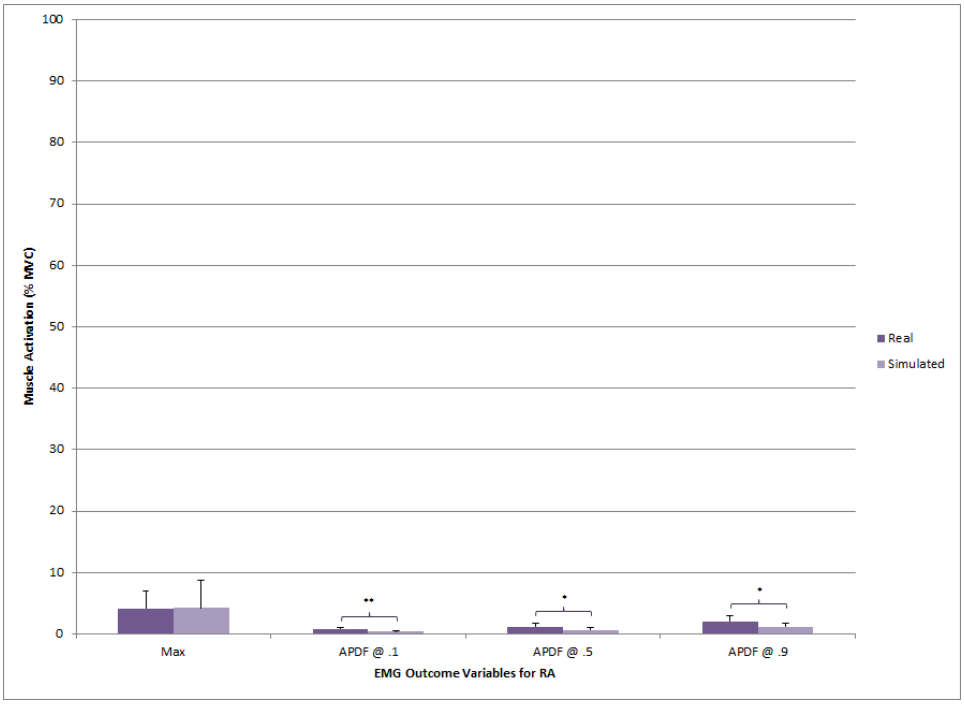


Fig. 56. Real and simulated fMISS1 comparison results for female RA electromyography outcome variables.
Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$. The vertical error bars represent one standard deviation of the average muscle activity for each outcome variable.

For fSIDE (Fig. 57 and Fig. 58), the % MVC of LD values achieved during the real (4.29 ± 2.35 % MVC and 8.93 ± 6.61 % MVC, respectively) and simulated (2.07 ± 1.87 % MVC and 4.07 ± 2.90 % MVC, respectively) versions of fQUAD2 at amplitude probabilities of 0.1 (t=4.044, p=.004) and 0.5 (t=3.349, p=.010) were significantly different, as well as % MVC of RA values at an amplitude probability of 0.1 (1.08 ± .76 % MVC for real and 0.52 ± .29 % MVC for simulated; t=2.524, p=.036).

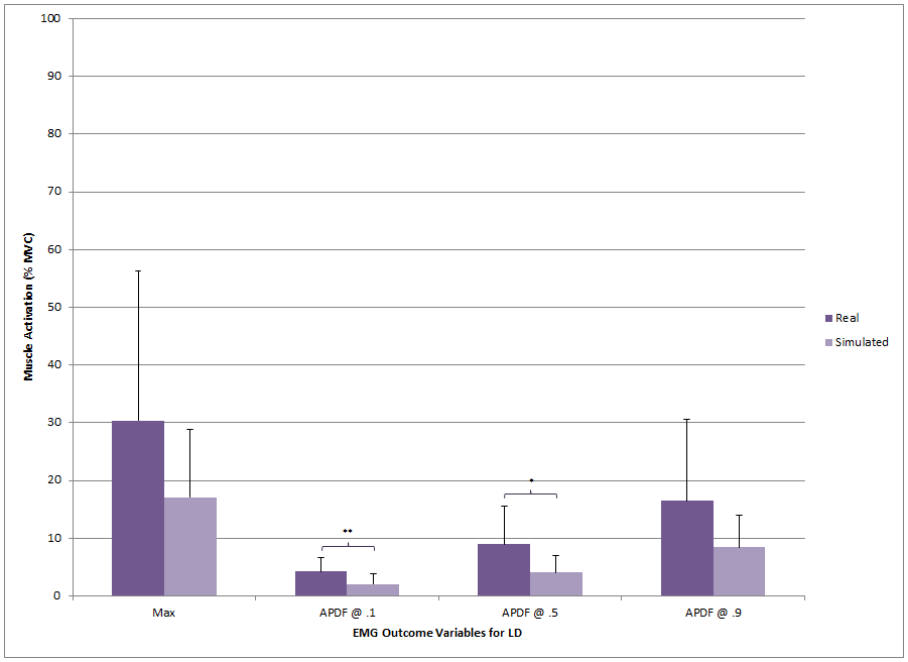


Fig. 57. Real and simulated fSIDE comparison results for female LD electromyography outcome variables.
Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$. The vertical error bars represent one standard deviation of the average muscle activity for each outcome variable.

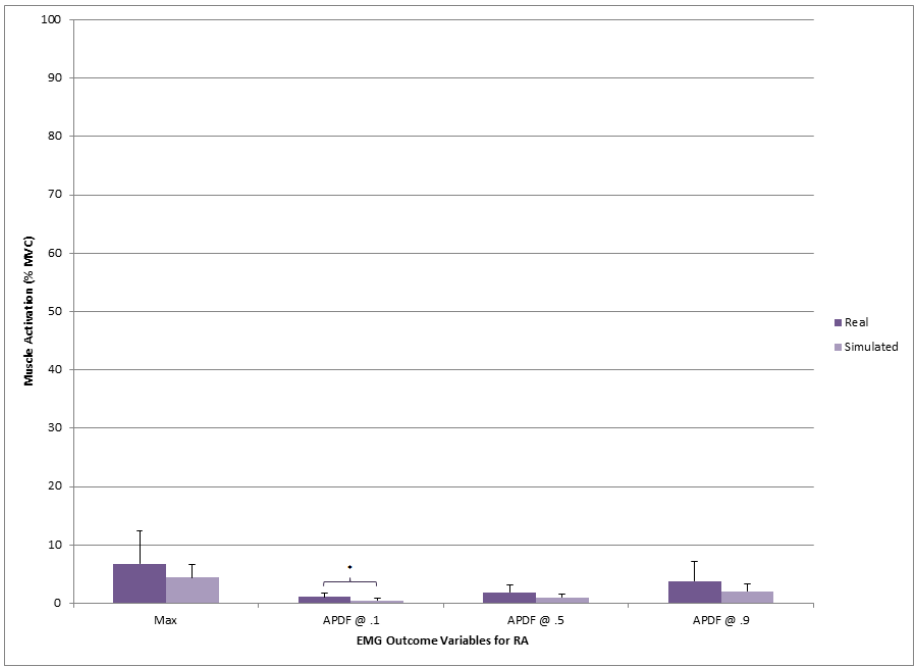


Fig. 58. Real and simulated fSIDE comparison results for female RA electromyography outcome variables.
Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$. The vertical error bars represent one standard deviation of the average muscle activity for each outcome variable.

Chapter 5
Discussion

While this study was first and foremost a descriptive study, hypotheses were also proposed and tested. They are specifically addressed subsequently. Not surprisingly, spine and hip motion and muscle activation are variable between people. This has implications not only for formal description, but also for making recommendations to individuals rather than simply constructing a generic guide. This will provide future studies with some basis for study design that could range from population cohorts, to pained groups, to case studies. The discussion is organized to provide commentary and compare the data of this study with existing literature; general observations and hypotheses are addressed first. The limitations for interpretation of this data are also discussed followed by some parting conclusions and suggestions for clinicians dealing with pained patients experiencing these issues.

5.1 Coital position comparison

The main objective of this study was to describe male and female spine and hip kinematics and muscle activation patterns during common coital positions. The successful collection of kinematic and electromyography signals during this study demonstrates that a biomechanical analysis of coitus is feasible.

In general, the coital positions studied showed that, for both males and females, coitus is mainly a flexion-extension movement of the lumbar spine and hips. This initial observation supports impressions made from Schultz et al.'s (1999) MRI images of the anatomy of sexual intercourse (New Scientist [updated 2009]); although the lumbar spine was not specifically examined, the inherent repetitive flexion-extension movement was clearly seen in the mid-sagittal plane images. Therefore, the flexion-intolerant patient (e.g., intervertebral disc herniation), extension-intolerant patient (e.g., facet joint injury), and motion-intolerant patient are considered to be the most at risk for exacerbating their pain and symptoms during coitus. Another common trend across all coital positions was that males used a greater range of their spine and hip motion in comparison to females – albeit all coital positions studied were male-centric (i.e., males were in a dominant position and were at an advantage to control the coital movement). Furthermore, not one participant, regardless of gender, achieved 100 percent of their spine of hip aROM. Examining the movements and postures of common coital positions will aide in the assessment of how at risk these patients may be (i.e., how more or less 'spine-sparing' a coital position is) and, if deemed necessary, the development of initial recommendations for these back-pain sufferers. "Spine-sparing", for the purposes of this discussion, is intended to include avoiding the pain-provoking biomechanical variable – be that a motion or a posture that provokes pain.

Speed of this flexion-extension motion is one movement characteristic of coitus that will indicate a more or less spine-sparing coital movement. All five positions had speeds of over 1 Hz, which is highly repetitive. Based on this movement characteristic of coitus, all five positions are not considered benign for the discogenic patient, since flexion-extension motion of the

lumbar spine is occurring at highly repetitive rates across all five coital positions. To further qualify this observation, other kinematic variables must be compared to understand the range of spine aROM (i.e., amount of flexion and extension aROM) that this highly repetitive flexion-extension spine motion is occurring in. Regardless, one initial recommendation can be made: slowing the speed of coitus may reduce the risk of exacerbating low back pain and symptoms by decreasing the repetition of lumbar spine flexion-extension motion.

Flexion has been shown to cause posterior migration of the nucleus pulposus within the intervertebral disc (Fennel et al. 1996), increase compressive force on the fifth lumbar nerve root (Schnebel et al. 1989), and lower the compressive strength of the spine (Gunning et al. 2001), therefore coital positions that reach high percentages of flexion aROM and low percentages of extension aROM are not considered 'spine-sparing', but rather pain-provoking. Since it was found that male and female lumbar spine movement during coitus was highly repetitive, and primarily consisting of flexion-extension movement, the less range that this spine movement is occurring in, the more spine-sparing a position is considered.

Based on this rationale, for males, both mSIDE and mMISS2 would be considered the least spine-sparing of the common coital positions studied and not recommended for the flexion-intolerant patient. Both mSIDE and mMISS2 reached the highest percentage of flexion aROM and used the widest range of flexion aROM over time. In an average penetration cycle, the maximum percentage of lumbar spine aROM achieved was lowest for mSIDE (i.e., remained in flexion) in comparison to the other positions. Furthermore, repetitive flexion-extension movements of the lumbar spine were occurring through the greatest range of flexion in mMISS2 during an average penetration cycle. Both variations of mQUAD, mQUAD1 and mQUAD2, would be considered the most spine-sparing of the coital positions studied, followed by mMISS1. Spine aROM during mQUAD2 remained in flexion; however, repetitive flexion-extension spine movement occurred through the least range of flexion. Clearly, contrary recommendations would be made for the extension-intolerant patient.

Using the same criteria for considering a coital position to be more or less spine-sparing for females, both variations of fMISS would not be recommended for the flexion-intolerant patient, as they are considered to be the least spine-sparing for these individuals. Both variations of fMISS were the only coital positions to use flexion aROM for flexion-extension motion. In an average penetration cycle, the maximum % aROM was highest for fQUAD2 and fSIDE (i.e., most extension) and lowest for both variations of fMISS (i.e., remained in flexion) and the minimum % aROM was lowest for both variations of fMISS (i.e., greatest flexion reached). Since, all coital positions had comparable ranges of motion that flexion-extension occurred in, fQUAD2 and fSIDE would be the most recommended coital positions for females with flexion-intolerance, followed by fQUAD1, and any variation of fMISS would be the least recommended. Again, for the extension-intolerant female patient, the reverse order would be recommended.

These initial recommendations contradict the most frequently advised coital position for both male and female patients with low back disorders (Osborne & Maruta 1980). Osborne and Maruta (1980) and White and Panjabi (1990) have both recommended the side-lying position (i.e., SIDELYING in this study) as the preferred position for coitus; based on a biomechanical

rationale, they presumed that this position would put the least amount of strain on the back. The guiding principle of White and Panjabi's (1990) biomechanical rationale – hyper-lordosis should be avoided because it may irritate the disc and nerve root – appears to be inconsistent with current knowledge of injury mechanisms that produce intervertebral disc herniations as well as other low back disorders. For example, they recommend that patients avoid coital positions where they are lying prone with hips and knees extended because it produces hyper-lordosis. In fact, extension has been shown to redirect displaced portions of the nucleus pulposus back to the central part of the intervertebral disc in prolapsed discs (Scannell & McGill 2009). Side-lying was considered to be "the best basic position for either partner with LBP" because flexing the hips and knees would relax the psoas and the sciatic nerve, straighten the spine, and reduce a disc bulge (White & Panjabi 1990). Current research on lumbar flexion has shown the contrary: straightening (i.e., flexing) the spine while flexing the knees and hips increases a disc bulge and tenses the sciatic nerve. In fact, the most common provocative test for sciatic nerve tension, the straight-leg raise (SLR) neural tension test, involves laying the patient supine and flexing the hip until sciatic nerve tension is subjectively reported (McGill 2007). Presumably, some spine flexion and subsequent increased pressure in the intervertebral disc contribute to the sciatic nerve tension in the SLR test. White and Panjabi (1990) do not mention QUADRUPED, which is the most recommended coital position for males and females with flexion-intolerance (in particular, mQUAD1 and fQUAD2, respectively), but they do recommend a general avoidance of MISSIONARY, which is somewhat supported by this study. For females, both variations of fMISS were found to be the least spine-sparing. It appears that the contradictory recommendations provided by this study and White and Panjabi (1990) are a result of fundamentally different biomechanical rationales that recommendations are based upon.

It is interesting to note that an apparently minor posture change – for example, changing upper body support from elbows to hands in the prone position for males and quadruped position for females and flexing to extending the hips and knees for females in the supine position – altered their respective lumbar spine kinematic profiles significantly. For both variations of fMISS, the change in the female spine kinematic profile is obvious: as the hips and knees are flexed (fMISS2), flexion in the lumbar spine increases. mMISS1 was among the more spine-sparing coital positions and mMISS2 was among the least. In the fQUAD2 posture, a greater percentage of extension aROM was achieved in an average penetration cycle than fQUAD1. Even a seemingly subtle change in the female's posture (i.e., fQUAD1 to fQUAD2) showed a change in the lumbar spine kinematic profile for mQUAD1 and mQUAD2. This indicates an effect of female posture on the male spine kinematic profile because mQUAD1 and mQUAD2 are presumably the same posture for the male. This interaction may be the result of a change in the penetration angle of the penis; in the missionary position, the penis reaches the anterior fornix with preferential contact of the anterior vaginal wall, but with rear-entry, the penis reaches the posterior fornix with preferential contact of the posterior vaginal wall (Faix et al. 2001). Perhaps, in addition to the method of entry changing the penetration angle, the female spine posture also affects the penetration angle and preferential contact of the penis, since the female spine achieved more extension in fQUAD2 than fQUAD1.

For males, it was expected that in coital positions that were more spine-sparing, a larger range of hip movement would be observed. This hypothesis is difficult to compare across positions because no previous work has been done to establish what average hip range would be for each coital position (that is, in part, the objective of this study). However, comparing hip movement between both variations of PRONE is an appropriate method to test this hypothesis, since mMISS1 was found to be among the more spine-sparing coital positions for males and mMISS2 was among the least. In an average penetration cycle, mMISS1 had a significantly higher maximum and minimum than mMISS2 and used a wider range of hip % aROM than mMISS2 – mMISS1 used far more hip extension. The hip kinematic profiles were certainly different between the two variations of PRONE, thus the hypothesis was supported. To ensure optimal spine-sparing technique for recommended coital positions, a hip-hinging technique (McGill 2007) can be taught to patients, so that male coital movement (i.e., thrusting) is hip-dominant and as spine-sparing as possible. Hip-hinging would be an easy technique to adopt in both variations of mQUAD as the movement pattern is essentially a kneeling squat. A similar relationship may exist between spine and knee movement during coitus; data will be analyzed further to investigate this relationship.

These movement and posture findings support the findings of qualitative studies on sexual activity and LBP and/or injury. These studies had shown that pain or discomfort during coitus was reported to be primarily due to mechanical factors, specifically, difficulty finding a position and difficulty with pelvic movements. Based on the above discussion, it is clear that these qualitative findings are supported by a biomechanical explanation.

Muscle activation patterns across all muscles were expected to differ significantly for males with the exception of the two variations of mQUAD and this was found to be true for LES, RA, and EO. Muscle activity was highly variable for both males and females, but muscle activity was higher overall for males – considering that males were shown to use a greater range of their spine and hip movement in comparison to females, this finding is not surprising. For males, coital movement appears to be gluteal-dominant in comparison to all muscles collected, biceps femoris in particular. Gluteus maximus activation levels were comparable to high-performance ballistic exercises studied in the same laboratory (i.e., same standardized protocol for electrode placement and eliciting maximum voluntary contractions from selected muscles of study participants), such as the kettle bell swing with (82.8 ± 44.2 % MVC) and without kime (i.e., a Japanese martial arts term for the instantaneous tensing of the abdominal muscles) (76.1 ± 36.6 % MVC), and the swing to snatch (58.1 ± 48.9 % MVC) (McGill & Marshall 2012). This warrants further investigation, especially in future studies where coital movement is being coached to encourage more hip hinging and less spine movement.

5.2 Simulated versus real coitus

A secondary objective was to determine if simulated coitus could be used in place of real coitus for future sex biomechanics research. Speed of penetration cycles for QUADRUPED1 (i.e., mQUAD1 for males and fQUAD1 for females), MISSIONARY2 (i.e., mMISS2 for males and fMISS2 for females), and SIDELYING (i.e., mSIDE for males and fSIDE for females) significantly differed from their simulated counterparts. Spine kinematics for mQUAD2, mSIDE,

fMISS1, fMISS2, and fSIDE were not well-represented by their simulated versions. Hip kinematics for mMISS1, mSIDE, fMISS1, and fSIDE significantly differed from their simulated versions. Muscle activity for mQUAD1 (i.e., obliques), mQUAD2 (i.e., obliques), mMISS1 (i.e., back, abdominals, obliques), mMISS2 (i.e., back, obliques, gluteals), mSIDE (i.e., abdominals), fQUAD1 (i.e., back, obliques, gluteals), fQUAD2 (i.e., abdominals), fMISS1 (i.e., abdominals), and fSIDE (latissimus dorsi and abdominals) significantly differed from their simulated versions. However, the majority of the differences in muscle activity between real and simulated coital positions found were not considered to be biologically significant differences. All coital positions were found to be significantly different from the simulated version on more than one outcome variable and most coital positions had differences in more than one area (i.e., spine and hip kinematics, muscle activity, and speed of penetration cycles). Thus, it is not recommended that simulated coitus is performed in place of real coitus for future research in sex biomechanics. However, the decision by the researcher ultimately will depend on the coital positions being studied and the outcome variable of interest.

Another comparison of interest is how representative actual coitus in the laboratory was to coitus that couples engaged in, in a private setting. Upon completion of the study, couples were asked to rate how representative they felt their experience in the laboratory setting was in comparison to their experiences in the privacy of their own home on a ten-point scale (1 being not representative at all and 10 being completely representative). This question was asked verbally. Couples deliberated and, with the exception of one couple, rated their experience in the laboratory at 7 or above.

5.3 Limitations

As with any study, limitations and assumptions are inherent and impinge the interpretation and relevance of the results. The most salient limitations are as follows:

- In the future, the administrator of the pre-study interview questionnaire should not be the principal investigator. They remained as unbiased as possible, but the administrator should not be the researcher who requires a particular sample size in a short amount of time. However, couples who participated subjectively reported experiencing a high level of comfort and professionalism with the research team.
- As previously mentioned, minimal slippage of the sacrum tracking cluster occurred in some of the male and female participants and an assumption was made that this occurred during the first simulated trial. Visual inspection of the kinematic signals confirmed this with most subjects. In the future, once participants are fully fitted with their instrumentation, they should be asked to simulate each position for a few seconds. The research team with re-check security of the instrumentation and then a calibration will be performed to re-establish the baseline.
- Muscle activity was only measured unilaterally for all subjects, given the availability of EMG channels. The assumption for healthy participants performing symmetrical movements was that left-sided muscle activity of the same sites would mirror those measured from the right side. Symmetrical muscle activation of healthy subjects has been demonstrated in previous work from our lab (McGill 1998). Mirrored muscle activity was

assumed for males and females in both QUADRUPED and MISSIONARY variations, but not SIDELYING – the trunk and hip muscle activity of the contralateral side of male and female participants during SIDELYING is not yet known.

- In *in vivo* experiments in biomechanics, encumbrance of the subjects is always a concern. This concern was anticipated, which was why couples were informally asked their comfort-level ten-point-scale question upon completion of the data collection. Out of the ten couples included in this study, nine rated their experience in the laboratory as representative of their experience at home as greater than or equal to seven on a ten-point scale (one being not representative at all and ten being completely representative). This also supports the fact that the presence of the researcher and research assistant during the data collection did not substantially affect their movement.
- Only male-centric coital positions were studied due to a limitation of instrumentation available. Future research should certainly investigate female-centric positions.
- Each coital position and variation was randomized before participants entered the laboratory on the day of data collection. However, all three couples who were assigned SIDELYING first, requested to next randomly-assigned position first. The couples reported least familiarity with SIDELYING and difficulty initiating penile penetration in that position.
- The data from some couples for MISSIONARY also had to be excluded. Despite proper cueing and visual aids throughout the data collection, some females did not perform MISSIONARY1, but instead performed MISSIONARY2 and another variation with their hips and knees flexed, but feet not in contact with the bed. For future studies, it is recommended that couples be asked to demonstrate the simulated positions in front of the researcher before beginning the data collection.
- During the data collection itself, the researcher was unable to visually confirm that actual coitus was taking place. Additional clusters were placed on addition upper and lower limb segments as well as the head to remain as oriented as possible throughout the collection in the virtual collection space. The research team has no reason to believe that real coitus did not take place with any of the participants.
- The magnitudes of lumbar spine compression and shear were not considered in the initial recommendations made. Since these loads may differ between positions, recommendations may differ from those made based on kinematics alone. Furthermore, other motions that may exacerbate LBP were not considered (i.e., intolerance to torsion and / or lateral flexion).
- Finally, the coital positions were performed by participants that did not have a pre-existing disabling back or hip condition, but the recommendations being made are for a clinical setting where recommendations will typically be given to patients with a low back injury who may have different movement patterns during coitus. As stated throughout the document, this study was meant to provide initial recommendations based on a biomechanical analysis in an area that had not previously been explored. This is a starting point for recommendations to evolve from, but evidence-based guidance, even if it is based on a healthy population, is an improvement from resources health care practitioners are currently relying on for this issue.

Chapter 6

Conclusions

In summary, this first study on human coitus examining spine and hip kinematics and muscle activation patterns has shown that it is feasible to collect kinematic and electromyography signals during coitus and that flexion-extension motion of the spine and hips, in both males and females, is probably of most concern for those who experience pain. The above biomechanical analysis of common coital positions may be useful in a clinical context. When a patient presents to a health care practitioner with flexion-intolerance from various causes, they are typically advised to avoid common activities of daily living (ADLs), including sitting, bending, and lifting. Based on the highly repetitive flexion-extension motion of the male and female lumbar spine during coitus, it is recommended that during the acute stage of a low back injury resulting in flexion-, extension-, or motion-intolerance, that coitus be added to this common list of ADLs to be avoided. If the LBP is a more chronic issue, particular common coital positions should be avoided.

For the flexion-intolerant male patient, avoid mSIDE and mMISS2 as they have been shown to require the most flexion. Both variations of mQUAD are the more spine-sparing of coital positions followed by, mMISS1. Coaching the male patient on proper hip-hinging technique while thrusting – an easy technique to incorporate in both variations of mQUAD – will likely decrease spine movement and increase the spine-sparing quality of mQUAD.

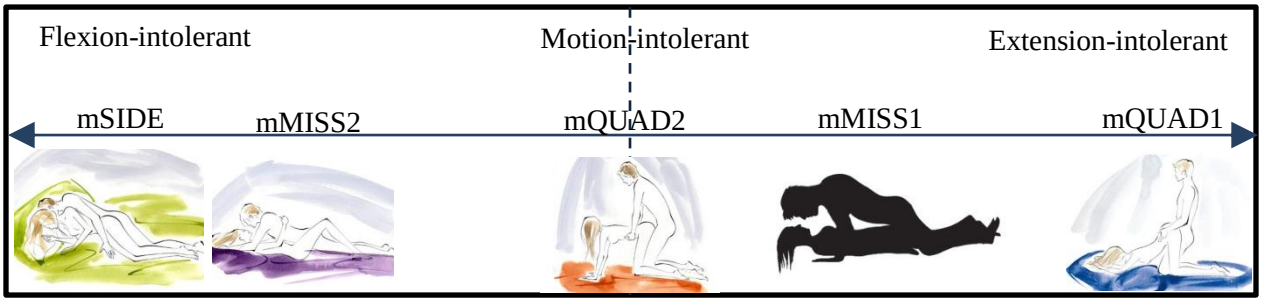


Fig. 59. Initial recommendations for male coital positions to avoid for specific LBP-provoking movements

Note: Motions, postures, and loads may exacerbate LBP. Only specific motions were analyzed in this study; therefore, recommendations can only be made for these specific motion intolerances (i.e., flexion-, extension-, and motion-intolerance [in the sagittal plane]).

For the flexion-intolerant female patient, avoid both variations of fMISS, especially with hip and knee flexion (fMISS2), as they have been shown to be the least spine-sparing. fQUAD2 and fSIDE are the more spine-sparing coital positions, followed by fQUAD1.

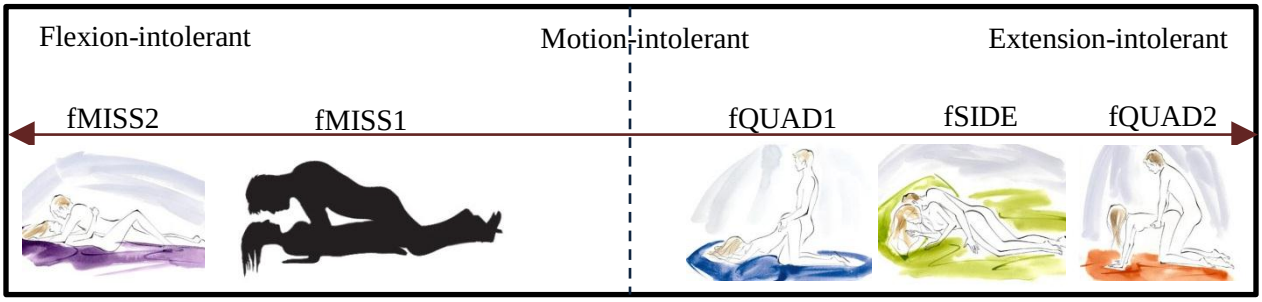


Fig. 60. Initial recommendations for female coital positions to avoid for specific LBP-provoking movements.
Note: Motions, postures, and loads may exacerbate LBP. Only specific motions were analyzed in this study; therefore, recommendations can only be made for these specific motion intolerances (i.e., flexion-, extension-, and motion-intolerance [in the sagittal plane]).

Seemingly minor posture changes for a coital position should not be considered lightly; these can change the spine kinematic profile significantly, resulting in a coital position that was considered spine-sparing becoming a position that should be avoided. Thus, spine-sparing coitus appears to be possible for the flexion-, extension-, and motion-intolerant patient. Health care practitioners may recommend appropriate coital positions and coach coital movement patterns, such as speed control and hip-hinging.

With respect to future research in the area of sex biomechanics, using simulated coitus in replace of real coitus is not justifiable according to the data of this study. However, including a simulated condition did prove beneficial for increasing the comfort level of the couples and allowing time to practice the experimental protocol. Future directions may address female-centric positions (e.g., 'reverse missionary' with male supine and female seated on top), and back-pained patients with and without an intervention (e.g., movement pattern coaching or aides, such as a lumbar support).

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Appendix A

Pre-screening Interview Questionnaire

Investigator – Thank you for coming to speak with me today. We ask that every potential participant comes in for this preliminary visit, so that you have an opportunity to see the lab and ask me any questions that you may have and I may get to know a little bit more about you and your partner. It's very important for you to know that anything we talk about today will not be shared with anyone, including your partner.

1.
    a. How long have you and your partner been together?
    b. How long have you and your partner been in a sexual relationship together?
2. When you and your partner are faced with a decision, how do you work through it?
3. When you and your partner disagree, how do you resolve the conflict?
4.
    a. Do you feel that your sexual life with your partner is satisfactory?
    b. Do you feel that you can comfortably talk to your partner about your sexual life?
5.
    a. Have you and your partner discussed participating in this study?
    b. Do you wish to participate?
    c. If so, why?
    d. Do you feel comfortable participating in this study?
6.
    a. If, in the middle of the study, you decided that you no longer wanted to participate and wanted to withdraw your consent, would you let your partner know?
    b. How would you convey this?
    c. You know your partner very well. What do you think their response would be?
    d. What do you think the researcher's response would be?
7. If the roles were reversed and it was your partner that no longer wanted to participate and wanted to withdraw consent, how would you respond?
8. What would help you to feel comfortable in the laboratory environment – what would make the setting less "lab-like"?
9. I've asked you a lot of questions – many, very personal – and I appreciate your willingness to share with me. Now, do you have any questions for me?
10. Given all of the things that we have discussed during this interview, are you sure you would like to participate in the study? If you decide that you would not like to participate in the study, I will not tell your partner that you are uncomfortable participating. Rather, I will just contact both of you within three business days and let you know that I will not need your participation in the study at this time.

Thank you again for meeting with me today. We will be contacting you within three business days to let you know if we will be asking you to participate in this study with your partner.

Student Investigator: Initial here_____ when age of potential participant has been verified through government-issued photographic identification to be 18 years of age or older.

Appendix B

Table 7. Male lumbar spine kinematic results for real and simulated versions of mQUAD1.

		Real				*Simulated*					
Outcome Variable		n	Median	Mean	Std. dev.	N	Median	Mean	Std. dev.	*t*	*p*
Avg max	deg	7	-.25	-1.08	9.31	9	2.28	.94	5.99		
	% aROM	7	5.15	15.04	34.96	9	13.46	15.27	20.76	.215	.838
Avg min	deg	7	-4.74	-10.23	14.58	9	-3.19	-4.67	7.54		
	% aROM	7	-10.20	-8.61	31.33	9	-4.98	-2.65	14.75	.859	.430
APDF @ 0.1	% aROM	10	-23.23	-22.01	21.61	10	-15.55	-12.06	13.69	-2.018	.074
APDF @ 0.5	% aROM	10	-15.83	-9.90	26.16	10	-7.34	-1.29	17.90	-1.454	.180
APDF @ 0.9	% aROM	10	-9.65	5.55	35.84	10	12.45	10.90	20.92	-.682	.513
Avg amplitude diff	deg	7	6.79	9.15	7.25	9	6.39	5.62	2.12		
	% aROM	7	16.23	23.68	19.54	9	12.92	17.91	10.15	1.544	.183

Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$.

Table 8. Male lumbar spine kinematic results for real and simulated versions of mQUAD2.

		Real				*Simulated*					
Outcome Variable		n	Median	Mean	Std. dev.	N	Median	Mean	Std. dev.	*t*	*p*
Avg max	deg	7	-6.55	-7.67	9.07	8	1.77	.32	9.63		
	% aROM	7	-12.33	-9.16	14.22	8	13.90	20.96	33.91	-2.167	.082
Avg min	deg	7	-12.26	-15.80	12.20	8	-2.62	-7.90	15.21		
	% aROM	7	-21.05	-22.46	15.99	8	-3.00	-1.95	30.95	-2.001	.102
APDF @ 0.1	% aROM	10	-27.67	-24.95	15.60	10	-13.37	-10.22	25.53	-2.570	$.030^{*}$
APDF @ 0.5	% aROM	10	-20.00	-12.54	21.02	10	-3.24	2.27	26.00	-2.510	$.033^{*}$
APDF @ 0.9	% aROM	10	-10.37	-.78	27.15	10	13.63	17.70	31.91	-2.346	$.044^{*}$
Avg amplitude diff	deg	7	4.74	8.10	8.15	8	4.85	8.19	8.42		
	% aROM	7	7.40	13.26	11.52	8	16.97	22.87	16.98	-1.528	.187

Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$

Table 9. Male lumbar spine kinematic results for real and simulated versions of mMISS1.

		Real				*Simulated*					
Outcome Variable		n	Median	Mean	Std. dev.	n	Median	Mean	Std. dev.	*t*	*p*
Avg max	deg	7	6.83	-1.52	17.11	7	7.31	11.34	17.48		
	% aROM	7	19.10	13.98	42.83	7	37.96	39.80	36.99	-1.588	.173
Avg min	deg	7	-19.30	-16.23	15.11	7	-5.06	-6.22	19.35		
	% aROM	7	-31.87	-23.87	23.72	7	-7.65	-5.57	30.69	-2.253	.074
APDF @ 0.1	% aROM	9	-35.98	-28.58	22.33	10	-19.22	-17.37	27.43	-1.160	.280
APDF @ 0.5	% aROM	9	-10.40	-15.29	25.18	10	-12.12	2.22	34.42	-1.114	.298
APDF @ 0.9	% aROM	9	12.26	5.07	38.75	10	12.59	23.52	40.96	-.869	.410
Avg amplitude diff	deg	7	9.88	14.68	11.87	7	18.44	17.50	9.58		
	% aROM	7	13.72	37.86	35.43	7	35.56	45.22	28.57	-.871	.424

Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$

Table 10. Male lumbar spine kinematic results for real and simulated versions of mMISS2.

		Real				*Simulated*					
Outcome Variable		n	Median	Mean	Std. dev.	n	Median	Mean	Std. dev.	*t*	*p*
Avg max	deg	10	-1.21	-4.67	11.24	9	1.87	.40	10.75		
	% aROM	10	-.55	-.73	25.74	9	9.76	9.81	25.48	-.523	.615
Avg min	deg	10	-30.72	-28.14	13.82	9	-18.69	-22.90	12.78		
	% aROM	10	-53.35	-44.88	19.78	9	-37.80	-35.72	14.68	-1.555	.158
APDF @ 0.1	% aROM	10	-57.84	-49.97	19.91	10	-42.98	-42.68	16.30	-1.606	.143
APDF @ 0.5	% aROM	10	-29.27	-31.79	21.07	10	-22.99	-23.92	20.75	-1.114	.298
APDF @ 0.9	% aROM	10	-6.03	-7.02	25.04	10	.24	-2.19	28.94	.463	.654
Avg amplitude diff	deg	10	22.55	23.43	8.94	9	26.67	23.33	6.36		
	% aROM	10	46.86	44.10	17.55	9	38.52	45.54	19.96	.100	.923

Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$

Table 11. Male lumbar spine kinematic results for real and simulated versions of mSIDE.

		Real				*Simulated*					
Outcome Variable		n	Median	Mean	Std. dev.	n	Median	Mean	Std. dev.	*t*	*p*
Avg max	deg	9	-23.09	-23.10	14.86	9	-12.58	-15.76	13.53		
	% aROM	9	-33.36	-35.24	21.35	9	-20.73	-23.16	23.77	-1.302	.234
Avg min	deg	9	-37.56	-38.47	14.69	9	-30.94	-33.20	14.87		
	% aROM	9	-62.91	-60.97	15.60	9	-56.53	-52.04	20.93	-1.993	.086
APDF @ 0.1	% aROM	10	-68.67	-65.40	15.37	10	-62.41	-58.30	19.80	-2.357	.043*
APDF @ 0.5	% aROM	10	-56.59	-54.55	16.55	10	-51.14	-46.29	20.43	-2.352	.043*
APDF @ 0.9	% aROM	10	-36.85	-39.43	19.30	10	-34.35	-31.26	22.80	-1.725	.119
Avg amplitude diff	deg	9	16.37	15.38	7.73	9	20.03	17.58	8.41		
	% aROM	9	24.04	25.76	14.66	9	26.32	29.14	13.50	-.150	.885

Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$

Table 12. Male hip kinematic results for real and simulated versions of mQUAD1.

		Real				*Simulated*					
Outcome Variable		n	Median	Mean	Std. dev.	n	Median	Mean	Std. dev.	*t*	*p*
Avg max	deg	10	2.57	.36	7.86	10	-.74	-.80	8.28		
	% aROM	10	9.95	13.89	23.16	10	1.20	8.63	21.95	.747	.474
Avg min	deg	10	-12.07	-14.75	13.16	10	-14.51	-15.79	11.27		
	% aROM	10	-13.59	-11.58	21.10	10	-14.61	-16.76	10.91	.952	.366
APDF @ 0.1	% aROM	10	-10.04	-7.79	19.84	10	-12.28	-12.28	10.67	.907	.388
APDF @ 0.5	% aROM	10	-.64	3.09	21.38	10	-2.38	-3.14	8.44	1.195	.263
APDF @ 0.9	% aROM	10	12.73	19.49	25.22	10	5.63	12.76	19.73	.891	.396
Avg amplitude diff	deg	10	14.24	15.16	8.74	10	11.29	15.01	14.22		
	% aROM	10	24.63	25.55	9.27	10	15.69	25.41	24.64	.022	.983

Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$

Table 13. Male hip kinematic results for real and simulated versions of mQUAD2.

		Real				*Simulated*					
Outcome Variable		n	Median	Mean	Std. dev.	n	Median	Mean	Std. dev.	*t*	*p*
Avg max	deg	10	1.50	.05	9.16	10	1.75	-.25	9.38		
	% aROM	10	6.85	14.81	26.24	10	11.58	13.71	24.65	.361	.726
Avg min	deg	10	-15.16	-14.96	14.17	10	-11.61	-13.93	12.38		
	% aROM	10	-15.33	-11.71	20.78	10	-11.32	-14.35	13.23	.554	.593
APDF @ 0.1	% aROM	10	-11.86	-8.07	19.64	10	-7.47	-10.66	12.17	.579	.577
APDF @ 0.5	% aROM	10	-2.67	4.05	21.99	10	-.75	2.10	16.47	.575	.579
APDF @ 0.9	% aROM	10	9.39	19.78	27.30	10	15.27	19.46	26.49	.110	.915
Avg amplitude diff	deg	10	15.40	15.02	8.65	10	11.27	13.69	10.05		
	% aROM	10	21.62	26.51	12.20	10	24.94	28.07	17.96	-.359	.728

Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$

Table 14. Male hip kinematic results for real and simulated versions of mMISS1.

		Real				*Simulated*					
Outcome Variable		n	Median	Mean	Std. dev.	n	Median	Mean	Std. dev.	*t*	*p*
Avg max	deg	9	15.77	11.19	10.24	10	1.16	2.56	11.18		
	% aROM	9	54.81	56.38	36.13	10	11.95	25.98	35.81	3.196	.013*
Avg min	deg	9	-4.81	-12.97	10.53	10	-24.20	-23.84	15.73		
	% aROM	9	-4.89	-10.53	20.16	10	-24.41	-24.16	22.38	1.835	.104
APDF @ 0.1	% aROM	9	.86	-4.44	21.57	10	-20.42	-19.48	21.50	1.919	.091
APDF @ 0.5	% aROM	9	25.23	23.28	33.54	10	-8.49	-3.74	23.57	2.506	.037*
APDF @ 0.9	% aROM	9	58.24	58.65	37.12	10	11.79	28.99	37.30	2.800	.023*
Avg amplitude diff	deg	9	21.28	24.18	10.49	10	26.40	26.38	8.36		
	% aROM	9	70.05	67.03	21.16	10	47.11	50.12	22.31	2.233	.056

Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$

Table 15. Male hip kinematic results for real and simulated versions of mMISS2.

		Real				*Simulated*					
Outcome Variable		n	Median	Mean	Std. dev.	n	Median	Mean	Std. dev.	*t*	*p*
Avg max	deg	10	-2.54	-1.56	10.80	10	-6.63	-3.80	9.84		
	% aROM	10	-2.66	8.71	27.21	10	-7.21	5.34	23.88	.444	.667
Avg min	deg	10	-28.53	-33.19	14.82	10	-35.39	-34.05	10.88		
	% aROM	10	-33.45	-36.14	15.89	10	-38.67	-36.99	13.41	.139	.892
APDF @ 0.1	% aROM	10	-27.64	-30.49	15.85	10	-32.95	-31.10	13.12	.103	.920
APDF @ 0.5	% aROM	10	-9.97	-12.94	13.88	10	-17.16	-15.83	11.31	.550	.596
APDF @ 0.9	% aROM	10	2.65	12.25	25.67	10	-2.99	9.57	24.48	.315	.760
Avg amplitude diff	deg	10	33.76	31.60	10.12	10	30.03	30.30	8.38		
	% aROM	10	39.73	44.81	21.92	10	35.16	42.49	20.05	.539	.603

Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$

Table 16. Male hip kinematic results for real and simulated versions of mSIDE.

		Real				*Simulated*					
Outcome Variable		n	Median	Mean	Std. dev.	n	Median	Mean	Std. dev.	*t*	*p*
Avg max	deg	10	-1.25	-4.85	12.29	10	-14.40	-12.65	12.88		
	% aROM	10	1.02	5.53	26.33	10	-14.61	-10.88	20.26	1.819	.102
Avg min	deg	10	-32.09	-29.61	10.93	10	-43.44	-41.70	13.17		
	% aROM	10	-33.85	-31.38	10.15	10	-43.51	-44.57	12.83	7.057	$<.001^{***}$
APDF @ 0.1	% aROM	10	-28.35	-26.23	9.93	10	-37.28	-38.81	12.38	6.303	$<.001^{***}$
APDF @ 0.5	% aROM	10	-12.09	-10.97	11.11	10	-22.65	-23.38	12.30	3.387	$.008^{**}$
APDF @ 0.9	% aROM	10	3.55	9.42	25.66	10	-9.35	-6.65	18.87	1.838	.099
Avg amplitude diff	deg	10	23.63	24.76	9.88	10	29.65	29.12	13.40		
	% aROM	10	31.44	36.90	24.97	10	33.25	33.77	15.53	.381	.712

Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$

Table 17. Male electromyography signal results for real and simulated versions of mQUAD1.

		Real				*Simulated*					
Outcome Variable		n	Median	Mean	Std. dev.	n	Median	Mean	Std. dev.	*t*	*p*
UES											
Max	% MVC	10	9.84	10.71	6.36	10	7.99	8.45	5.13	.862	.411
APDF @ 0.1	% MVC	7	.60	1.03	1.26	5	.50	.46	.30	1.303	.263
APDF @ 0.5	% MVC	10	1.78	2.17	1.68	10	1.20	1.33	.93	1.440	.184
APDF @ 0.9	% MVC	10	5.03	5.00	2.80	10	4.08	3.94	2.88	.827	.429
LES											
Max	% MVC	10	19.11	20.15	9.15	10	17.23	19.49	10.95	.141	.891
APDF @ 0.1	% MVC	10	2.10	2.36	2.27	9	1.53	2.10	2.26	-.577	.579
APDF @ 0.5	% MVC	10	6.38	5.75	3.38	10	4.83	5.31	3.95	.321	.756
APDF @ 0.9	% MVC	10	11.92	11.64	5.19	10	9.29	10.57	7.26	.449	.664
LD											
Max	% MVC	10	13.39	32.88	44.84	10	8.61	17.10	16.22	1.480	.173
APDF @ 0.1	% MVC	10	1.12	1.75	1.79	8	.68	1.59	2.13	.594	.571
APDF @ 0.5	% MVC	10	3.01	7.70	10.27	9	1.90	3.65	4.73	1.702	.127
APDF @ 0.9	% MVC	10	7.57	17.71	23.21	9	4.88	8.47	8.66	1.757	.117
RA											
Max	% MVC	10	5.67	8.48	8.28	10	3.93	7.77	7.93	.239	.816
APDF @ 0.1	% MVC	8	1.46	1.43	.99	7	.30	.88	1.01	2.290	.062
APDF @ 0.5	% MVC	10	2.16	2.32	2.38	10	.84	1.47	1.53	1.749	.114
APDF @ 0.9	% MVC	10	3.01	4.82	5.36	10	2.31	3.49	3.59	.988	.349
EO											
Max	% MVC	10	9.06	14.45	14.12	9	4.57	12.28	17.03	1.432	.190
APDF @ 0.1	% MVC	10	1.67	3.99	5.47	9	1.02	2.43	3.31	2.045	.075
APDF @ 0.5	% MVC	10	2.75	6.03	7.58	9	1.57	4.44	6.40	2.711	.027*
APDF @ 0.9	% MVC	10	4.85	9.03	10.19	9	2.28	7.39	11.16	2.397	.043*
IO											
Max	% MVC	10	36.43	42.01	27.04	9	20.51	23.79	16.95	1.853	.101
APDF @ 0.1	% MVC	10	8.32	9.29	6.87	9	4.15	5.53	3.68	1.730	.122

APDF @ 0.5	% MVC	10	11.07	17.20	14.45	9	8.31	8.48	4.85	2.025	.077
APDF @ 0.9	% MVC	10	21.56	27.48	20.38	9	12.00	13.21	7.03	2.317	.049*
GMax											
Max	% MVC	9	31.30	69.86	105.47	8	36.47	40.52	33.77	1.185	.275
APDF @ 0.1	% MVC	9	2.81	10.77	24.31	8	2.77	3.81	3.25	.956	.371
APDF @ 0.5	% MVC	9	7.19	21.38	41.84	8	7.01	9.88	8.20	1.011	.346
APDF @ 0.9	% MVC	9	16.15	41.79	74.41	8	17.77	22.84	20.61	1.059	.325
BF											
Max	% MVC	10	7.18	9.54	6.49	9	4.88	7.06	7.54	1.508	.170
APDF @ 0.1	% MVC	10	1.19	1.24	.63	8	.53	1.22	1.41	.016	.987
APDF @ 0.5	% MVC	10	2.18	2.32	1.08	9	1.29	2.13	2.61	.161	.876
APDF @ 0.9	% MVC	10	3.64	4.25	2.46	9	3.06	4.12	5.20	.051	.960

Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$

Table 18. Male electromyography signal results for real and simulated versions of mQUAD2.

		Real				*Simulated*					
Outcome Variable		n	Median	Mean	Std. dev.	n	Median	Mean	Std. dev.	*t*	*p*
UES											
Max	% MVC	10	8.97	9.69	6.98	10	8.30	10.11	6.62	-.193	.852
APDF @ 0.1	% MVC	8	.43	.78	.91	6	.47	.83	.98	-.325	.758
APDF @ 0.5	% MVC	10	1.36	1.88	1.67	10	1.40	2.09	1.95	-.400	.699
APDF @ 0.9	% MVC	10	4.48	4.76	3.11	10	3.16	4.81	3.73	-.053	.959
LES											
Max	% MVC	10	19.39	17.61	6.88	9	19.25	18.31	8.39	-.082	.937
APDF @ 0.1	% MVC	9	1.84	2.35	2.02	8	1.61	1.71	1.44	1.180	.277
APDF @ 0.5	% MVC	10	4.71	5.06	2.74	9	5.85	5.49	2.44	-.454	.662
APDF @ 0.9	% MVC	10	11.40	10.84	3.88	9	11.87	10.90	5.14	.075	.942
LD											
Max	% MVC	10	11.90	21.03	21.07	10	12.85	16.27	10.88	.865	.410
APDF @ 0.1	% MVC	10	.67	1.47	1.63	9	.56	.91	.82	1.318	.224
APDF @ 0.5	% MVC	10	2.61	5.32	5.89	9	2.20	3.68	3.66	.656	.530
APDF @ 0.9	% MVC	10	6.33	11.54	13.07	10	5.51	8.24	7.28	.869	.408
RA											
Max	% MVC	10	6.67	7.63	5.17	10	5.85	6.46	5.18	.629	.545
APDF @ 0.1	% MVC	10	1.29	1.11	1.00	9	.42	.84	.94	1.735	.121
APDF @ 0.5	% MVC	10	2.11	1.94	1.60	10	1.46	1.46	1.18	1.044	.324
APDF @ 0.9	% MVC	10	3.20	3.81	3.13	10	2.42	2.79	2.21	.999	.344
EO											
Max	% MVC	10	8.14	14.89	16.05	10	4.88	11.96	18.55	1.798	.106
APDF @ 0.1	% MVC	10	1.67	3.84	5.41	10	.93	2.59	3.90	2.173	.058
APDF @ 0.5	% MVC	10	2.53	6.03	8.63	10	1.50	4.89	8.02	2.576	.030*
APDF @ 0.9	% MVC	10	3.79	8.69	11.28	10	2.51	7.37	11.71	1.971	.080
IO											
Max	% MVC	10	33.19	42.22	27.40	10	23.35	23.63	11.89	1.976	.080
APDF @ 0.1	% MVC	10	7.64	8.54	5.53	10	3.55	5.38	3.40	1.695	.124

APDF @ 0.5	% MVC	10	12.39	15.39	9.70	10	8.07	9.15	4.64	2.003	.076
APDF @ 0.9	% MVC	10	19.03	25.28	16.80	10	15.62	14.38	7.15	1.992	.077
GMax											
Max	% MVC	9	29.75	66.36	83.52	9	37.86	41.85	37.71	1.448	.186
APDF @ 0.1	% MVC	9	3.29	10.79	22.21	9	3.48	5.97	7.63	.955	.367
APDF @ 0.5	% MVC	9	7.74	20.31	33.84	9	7.22	11.76	12.70	1.176	.273
APDF @ 0.9	% MVC	9	15.41	37.98	53.34	9	19.05	24.40	23.45	1.290	.233
BF											
Max	% MVC	10	6.01	6.98	4.29	9	6.00	8.61	8.05	-.574	.582
APDF @ 0.1	% MVC	10	1.20	1.17	.50	9	.54	.71	.53	1.912	.092
APDF @ 0.5	% MVC	10	2.28	2.25	.92	9	1.06	1.55	1.33	1.808	.108
APDF @ 0.9	% MVC	10	3.52	4.11	2.37	9	2.90	3.28	2.84	1.769	.115

Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$

Table 19. Male electromyography signal results for real and simulated versions of mMISS1.

		Real				*Simulated*					
Outcome Variable		n	Median	Mean	Std. dev.	n	Median	Mean	Std. dev.	*t*	*p*
UES											
Max	% MVC	9	6.01	5.21	2.48	8	2.77	3.76	2.06	1.203	.268
APDF @ 0.1	% MVC	8	.87	.91	.58	7	.54	.53	.36	4.721	.003**
APDF @ 0.5	% MVC	8	1.61	1.67	.82	8	.78	.98	.71	4.606	.002**
APDF @ 0.9	% MVC	8	3.32	2.97	1.39	9	1.24	1.59	1.18	2.832	.025*
LES											
Max	% MVC	9	4.01	4.84	3.29	8	3.42	4.29	2.97	.538	.607
APDF @ 0.1	% MVC	9	.44	.59	.54	8	.28	.36	.32	3.593	.009**
APDF @ 0.5	% MVC	9	.72	1.15	.97	8	.47	.65	.47	2.427	.046*
APDF @ 0.9	% MVC	9	1.19	2.15	1.89	8	1.45	1.38	.73	1.455	.189
LD											
Max	% MVC	9	8.50	13.44	12.08	8	7.77	12.35	10.58	.508	.627
APDF @ 0.1	% MVC	9	1.79	2.93	2.71	8	1.19	1.59	1.30	2.271	.057
APDF @ 0.5	% MVC	9	3.18	5.63	5.25	8	3.24	3.75	3.12	1.846	.107
APDF @ 0.9	% MVC	9	4.94	8.86	8.65	8	4.93	6.60	5.57	1.341	.222

RA											
Max	% MVC	9	33.80	37.22	21.17	8	22.84	29.92	23.22	.905	.395
APDF @ 0.1	% MVC	8	6.18	6.28	4.32	8	2.60	2.92	2.49	2.657	.033*
APDF @ 0.5	% MVC	9	9.47	11.76	8.83	8	6.87	7.18	4.15	2.080	.076
APDF @ 0.9	% MVC	9	18.21	23.79	17.05	8	14.48	16.27	9.24	1.417	.199
EO											
Max	% MVC	9	47.47	41.65	29.95	8	16.81	22.28	21.63	2.221	.062
APDF @ 0.1	% MVC	9	2.03	8.25	10.43	8	1.43	2.52	2.46	1.766	.121
APDF @ 0.5	% MVC	9	13.89	14.62	13.07	8	3.47	6.10	5.18	2.174	.066
APDF @ 0.9	% MVC	9	30.00	26.99	21.55	8	6.67	12.55	12.42	2.272	.057
IO											
Max	% MVC	9	33.52	33.20	24.19	8	16.35	17.86	9.79	2.012	.084
APDF @ 0.1	% MVC	9	4.23	5.99	5.31	8	1.46	2.30	1.93	2.235	.061
APDF @ 0.5	% MVC	9	8.72	10.53	7.52	8	3.11	4.37	2.74	2.893	.023*
APDF @ 0.9	% MVC	9	14.37	18.60	13.13	8	6.98	8.17	3.90	2.939	.022*
GMax											
Max	% MVC	8	22.99	46.86	64.94	7	5.21	9.12	11.22	1.577	.166
APDF @ 0.1	% MVC	5	.43	2.16	4.19	4	.09	1.28	2.89	1.111	.348
APDF @ 0.5	% MVC	8	1.04	3.84	5.87	7	.28	1.14	2.62	1.774	.126
APDF @ 0.9	% MVC	8	10.05	22.75	38.63	7	1.34	3.05	3.85	1.417	.206
BF											
Max	% MVC	9	15.21	29.27	38.80	7	5.59	23.90	43.56	1.863	.112
APDF @ 0.1	% MVC	7	.49	.70	.75	5	.13	.86	1.41	-.947	.397
APDF @ 0.5	% MVC	9	1.17	1.78	1.61	5	1.81	2.67	2.71	-1.073	.344
APDF @ 0.9	% MVC	9	8.46	8.66	8.62	7	1.75	12.22	26.52	-.682	.521

Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$

Table 20. Male electromyography signal results for real and simulated versions of mMISS2.

		Real				*Simulated*					
Outcome Variable		n	Median	Mean	Std. dev.	n	Median	Mean	Std. dev.	*t*	*p*
UES											
Max	% MVC	10	5.65	5.72	2.91	9	3.81	4.49	2.08	1.029	.334
APDF @ 0.1	% MVC	8	1.24	1.02	.61	8	.36	.60	.52	2.382	.049*
APDF @ 0.5	% MVC	8	2.07	1.89	.95	8	.69	1.02	.65	2.925	.022*
APDF @ 0.9	% MVC	10	2.49	2.83	1.89	8	1.38	1.76	.85	2.594	.036*
LES											
Max	% MVC	10	6.18	7.47	5.71	9	3.94	4.84	3.45	.765	.466
APDF @ 0.1	% MVC	9	.65	.55	.38	7	.31	.32	.19	3.307	.016*
APDF @ 0.5	% MVC	10	1.05	1.09	.84	9	.50	.52	.35	3.270	.011*
APDF @ 0.9	% MVC	10	2.25	2.41	2.04	9	1.19	1.13	.71	2.321	.049*
LD											
Max	% MVC	10	8.74	27.24	36.07	9	4.93	16.37	21.51	2.155	.063
APDF @ 0.1	% MVC	10	2.57	6.80	8.72	8	1.75	4.80	8.06	1.122	.299
APDF @ 0.5	% MVC	10	3.98	10.85	14.09	9	2.32	6.88	9.99	1.543	.161
APDF @ 0.9	% MVC	10	6.60	16.06	20.27	9	3.58	11.28	15.42	2.056	.074
RA											
Max	% MVC	10	33.24	33.93	23.67	9	9.14	22.49	30.08	1.142	.286
APDF @ 0.1	% MVC	9	1.11	1.38	1.25	8	.68	1.24	1.40	1.824	.111
APDF @ 0.5	% MVC	10	3.90	5.73	6.07	9	1.00	2.82	3.94	2.100	.069
APDF @ 0.9	% MVC	10	16.87	17.40	15.17	9	3.66	7.63	8.91	2.169	.062
EO											
Max	% MVC	10	20.95	29.02	22.51	9	8.89	17.50	16.27	3.020	.017*
APDF @ 0.1	% MVC	9	1.49	2.43	2.48	7	.67	1.20	.97	1.787	.124
APDF @ 0.5	% MVC	10	5.18	6.98	7.07	9	4.16	3.25	2.55	2.346	.047*
APDF @ 0.9	% MVC	10	9.82	16.07	14.79	9	6.88	8.66	8.29	2.451	.040*
IO											
Max	% MVC	10	27.82	32.98	22.11	9	11.87	16.83	10.08	2.534	.035*
APDF @ 0.1	% MVC	10	1.54	2.86	3.41	8	1.09	1.44	1.50	2.598	.036*

APDF @ 0.5	% MVC	10	5.11	7.74	6.53	9	2.71	2.97	2.24	3.379	.010*
APDF @ 0.9	% MVC	10	15.78	16.51	10.70	9	5.62	7.45	4.72	3.097	.015*
GMax											
Max	% MVC	9	44.61	65.03	66.65	8	14.68	20.05	20.10	2.218	.062
APDF @ 0.1	% MVC	4	2.65	2.84	2.52	4	.11	1.26	2.86	.790	.487
APDF @ 0.5	% MVC	9	2.16	3.95	4.45	8	.43	1.22	2.66	3.129	.017*
APDF @ 0.9	% MVC	9	18.65	28.37	35.60	8	4.55	5.21	4.92	2.055	.079
BF											
Max	% MVC	10	19.47	38.94	60.63	8	13.77	13.20	7.35	1.225	.260
APDF @ 0.1	% MVC	5	.29	.76	.89	6	.17	.69	1.00	-.967	.405
APDF @ 0.5	% MVC	10	1.21	2.87	3.55	7	.58	1.52	1.67	1.646	.151
APDF @ 0.9	% MVC	10	10.88	14.86	18.79	8	3.26	4.78	4.35	1.393	.206

Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$

Table 21. Male electromyography signal results for real and simulated versions of mSIDE.

		Real				*Simulated*					
Outcome Variable		n	Median	Mean	Std. dev.	n	Median	Mean	Std. dev.	*t*	*p*
UES											
Max	% MVC	10	9.91	11.54	8.28	10	13.59	14.28	9.82	-.767	.463
APDF @ 0.1	% MVC	9	.87	1.82	3.23	9	1.31	1.59	1.26	.256	.805
APDF @ 0.5	% MVC	10	2.39	3.51	4.37	10	3.49	3.78	2.77	-.179	.862
APDF @ 0.9	% MVC	10	4.97	6.45	6.19	10	7.53	7.05	4.88	-.300	.771
LES											
Max	% MVC	10	10.91	12.15	6.77	10	11.48	12.92	7.67	-.222	.829
APDF @ 0.1	% MVC	9	.81	1.05	.84	8	.54	1.07	1.31	.182	.861
APDF @ 0.5	% MVC	10	1.78	2.11	1.78	10	1.27	1.85	2.22	.393	.704
APDF @ 0.9	% MVC	10	4.12	5.15	4.19	10	4.23	4.70	4.18	.254	.805
LD											
Max	% MVC	10	28.75	33.52	31.34	10	15.88	18.13	12.32	1.918	.087
APDF @ 0.1	% MVC	10	1.04	9.51	20.12	10	2.31	2.33	1.85	1.148	.281
APDF @ 0.5	% MVC	10	8.77	15.07	23.49	10	5.14	5.09	3.43	1.404	.194
APDF @ 0.9	% MVC	10	17.18	22.70	27.15	10	9.66	9.25	5.93	1.758	.113

RA											
Max	% MVC	10	19.27	17.38	11.91	10	9.02	11.55	8.28	2.312	.046*
APDF @ 0.1	% MVC	10	.73	1.45	1.79	9	.74	1.00	.92	1.098	.304
APDF @ 0.5	% MVC	10	1.85	3.12	3.05	10	1.84	2.16	1.60	1.231	.250
APDF @ 0.9	% MVC	10	7.33	8.29	5.79	10	4.26	5.30	3.58	1.886	.092
EO											
Max	% MVC	10	7.48	16.35	15.91	10	8.00	13.38	17.13	.577	.578
APDF @ 0.1	% MVC	9	.74	1.20	.93	8	1.12	1.17	1.03	.328	.752
APDF @ 0.5	% MVC	10	1.86	3.25	3.18	10	1.65	2.54	3.07	.715	.493
APDF @ 0.9	% MVC	10	4.10	9.07	10.04	10	2.85	6.02	8.25	.961	.362
IO											
Max	% MVC	10	29.23	31.56	24.33	10	10.08	23.54	30.36	.725	.487
APDF @ 0.1	% MVC	10	2.25	2.98	2.05	9	1.05	2.55	3.32	.427	.681
APDF @ 0.5	% MVC	10	7.40	7.45	3.60	10	1.76	5.14	8.10	.777	.457
APDF @ 0.9	% MVC	10	17.56	14.79	6.99	10	3.93	11.25	17.07	.564	.587
GMax											
Max	% MVC	9	23.61	90.56	126.44	9	12.71	19.85	19.65	1.679	.132
APDF @ 0.1	% MVC	9	1.79	2.46	1.90	8	.75	1.44	2.23	1.672	.139
APDF @ 0.5	% MVC	9	5.01	12.42	15.83	9	1.68	2.35	2.33	2.191	.060
APDF @ 0.9	% MVC	9	13.81	40.06	62.53	9	5.69	7.13	7.23	1.599	.149
BF											
Max	% MVC	10	27.57	37.68	39.20	9	10.91	19.20	25.50	1.501	.171
APDF @ 0.1	% MVC	7	1.82	2.31	2.14	4	.49	.45	.38	2.434	.093
APDF @ 0.5	% MVC	10	4.01	8.11	10.83	9	1.58	2.43	4.04	1.444	.187
APDF @ 0.9	% MVC	10	11.60	21.48	27.36	9	4.28	8.46	13.67	1.378	.206

Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$

Table 22. Female lumbar spine kinematic results for real and simulated versions of fQUAD1.

		Real				*Simulated*					
Outcome Variable		n	Median	Mean	Std. dev.	n	Median	Mean	Std. dev.	*t*	*p*
Avg max	deg	8	5.86	5.54	8.43	8	6.00	6.39	6.50		
	% aROM	8	35.52	36.61	40.19	8	46.46	47.75	38.41	-1.642	.152
Avg min	deg	8	-1.21	-2.25	10.90	8	-2.03	.56	8.77		
	% aROM	8	-.55	.10	44.93	8	-6.81	15.20	44.60	-1.498	.185
APDF @ 0.1	% aROM	10	-1.66	-4.03	40.84	8	-9.41	9.03	43.89	-1.419	.190
APDF @ 0.5	% aROM	10	9.58	14.35	40.76	10	11.81	23.73	42.81	-1.351	.210
APDF @ 0.9	% aROM	10	29.33	35.29	43.99	10	26.76	28.06	35.95	-.607	.563
Avg amplitude diff	deg	8	5.00	7.79	8.42	8	5.54	5.76	3.69		
	% aROM	8	18.15	36.49	48.66	8	22.51	32.28	25.73	.304	.771

Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$

Table 23. Female lumbar spine kinematic results for real and simulated versions of fQUAD2.

		Real				*Simulated*					
Outcome Variable		n	Median	Mean	Std. dev.	n	Median	Mean	Std. dev.	*t*	*p*
Avg max	deg	8	14.60	12.92	8.30	5	9.59	7.94	8.77		
	% aROM	8	84.56	66.72	36.80	5	87.69	63.13	46.91	.062	.954
Avg min	deg	8	12.04	7.48	10.07	5	3.81	1.90	11.41		
	% aROM	8	59.40	41.17	43.49	5	28.79	25.54	46.71	.941	.400
APDF @ 0.1	% aROM	10	46.25	29.96	46.25	9	21.18	29.89	44.87	.010	.992
APDF @ 0.5	% aROM	10	72.87	52.40	44.45	10	55.47	49.43	44.45	.669	.520
APDF @ 0.9	% aROM	10	89.33	67.49	45.65	10	87.60	62.40	48.45	.560	.591
Avg amplitude diff	deg	8	5.78	5.44	4.25	5	4.27	6.05	3.23		
	% aROM	8	16.06	25.51	27.31	5	25.24	37.68	28.47	-2.687	.055

Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$

Table 24. Female lumbar spine kinematic results for real and simulated versions of fMISS1.

		Real				*Simulated*					
Outcome Variable		n	Median	Mean	Std. dev.	n	Median	Mean	Std. dev.	*t*	*p*
Avg max	deg	6	-7.99	-7.52	5.61	6	.44	1.27	3.51		
	% aROM	6	-22.19	-22.01	17.78	6	6.46	10.76	21.21	-4.873	.005**
Avg min	deg	6	-13.83	-14.00	5.23	6	-5.53	-4.57	2.52		
	% aROM	6	-40.62	-43.78	14.57	6	-14.52	-14.31	9.03	-7.584	.001**
APDF @ 0.1	% aROM	6	-36.77	-40.16	15.36	6	-10.19	-10.72	8.44	-6.501	.001**
APDF @ 0.5	% aROM	6	-25.45	-28.16	13.04	6	-1.04	1.33	10.76	-8.053	<.001***
APDF @ 0.9	% aROM	6	-15.03	-15.59	15.92	6	13.71	16.02	19.28	-4.703	.005**
Avg amplitude diff	deg	6	7.22	6.46	3.21	6	5.00	5.86	3.21		
	% aROM	6	18.44	21.70	13.61	6	21.01	25.18	18.79	-.482	.650

Statistical significance is represented by the following: *p<.05, **p<.01, ***p<.001

Table 25. Female lumbar spine kinematic results for real and simulated versions of fMISS2.

		Real				*Simulated*					
Outcome Variable		n	Median	Mean	Std. dev.	n	Median	Mean	Std. dev.	*t*	*p*
Avg max	deg	9	-15.30	-17.07	7.57	10	-13.93	-11.90	6.11		
	% aROM	9	-40.86	-44.42	14.47	10	-33.27	-33.46	16.33	-2.196	.059
Avg min	deg	9	7.65	-23.33	-22.99	10	-20.41	-18.90	6.53		
	% aROM	9	-60.40	-62.34	16.91	10	-5.346	-54.60	21.19	-2.950	.018*
APDF @ 0.1	% aROM	9	-55.89	-58.29	17.41	10	-49.37	-50.59	20.76	-3.019	.017*
APDF @ 0.5	% aROM	9	-51.18	-50.70	16.13	10	-41.46	-40.46	18.67	-3.422	.009**
APDF @ 0.9	% aROM	9	-38.22	-38.80	13.70	10	-27.38	-27.85	16.60	-2.370	.045*
Avg amplitude diff	deg	9	7.09	6.24	2.77	10	7.06	6.99	3.34		
	% aROM	9	18.08	17.86	10.27	10	19.40	21.10	13.48	.157	.879

Statistical significance is represented by the following: *p<.05, **p<.01, ***p<.001

Table 26. Female lumbar spine kinematic results for real and simulated versions of fSIDE.

		Real				*Simulated*					
Outcome Variable		n	Median	Mean	Std. dev.	n	Median	Mean	Std. dev.	*t*	*p*
Avg max	deg	9	4.48	6.48	7.29	8	1.48	2.54	5.18		
	% aROM	9	21.64	33.40	36.56	8	11.26	20.13	29.99	1.076	.318
Avg min	deg	9	1.94	1.51	8.03	8	-5.58	-4.29	6.64		
	% aROM	9	11.14	12.09	36.67	8	-14.25	-8.77	29.63	3.057	.018*
APDF @ 0.1	% aROM	10	7.89	12.30	34.38	10	-6.94	-6.77	25.39	3.244	.010*
APDF @ 0.5	% aROM	10	18.84	26.65	35.97	10	2.77	7.27	25.60	2.886	.018*
APDF @ 0.9	% aROM	10	28.30	38.51	37.36	10	18.37	24.25	28.37	1.746	.115
Avg amplitude diff	deg	9	5.86	4.99	2.23	8	5.09	6.87	4.05		
	% aROM	9	17.39	21.39	9.72	8	29.49	29.05	16.65	-1.593	.155

Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$

Table 27. Female hip kinematic results for real and simulated versions of fQUAD1.

		Real				*Simulated*					
Outcome Variable		n	Median	Mean	Std. dev.	n	Median	Mean	Std. dev.	*t*	*p*
Avg max	deg	9	-68.89	-68.12	16.46	10	-63.88	-65.63	16.44		
	% aROM	9	-72.32	-73.35	13.12	10	-75.89	-75.03	17.98	-.153	.882
Avg min	deg	9	-74.54	-75.37	17.16	10	-70.33	-72.31	14.16		
	% aROM	9	-82.35	-81.20	12.81	10	-84.94	-82.73	15.67	-.068	.947
APDF @ 0.1	% aROM	10	-80.36	-78.84	12.25	10	-82.37	-79.70	15.09	.357	.729
APDF @ 0.5	% aROM	10	-73.56	-72.76	12.12	10	-76.12	-74.24	16.51	.490	.636
APDF @ 0.9	% aROM	10	-67.26	-67.45	12.75	10	-69.26	-68.25	18.15	.235	.819
Avg amplitude diff	deg	9	7.18	7.24	3.02	10	4.74	6.66	4.42		
	% aROM	9	7.53	7.83	3.30	10	5.13	7.67	4.93	-.246	.812

Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$

Table 28. Female hip kinematic results for real and simulated versions of fQUAD2.

		Real				*Simulated*					
Outcome Variable		n	Median	Mean	Std. dev.	n	Median	Mean	Std. dev.	*t*	*p*
Avg max	deg	9	-52.69	-57.32	17.75	10	-53.22	-52.43	12.79		
	% aROM	9	-60.06	-63.67	16.78	10	-61.79	-62.39	14.74	-.207	.841
Avg min	deg	9	-60.83	-63.50	18.51	10	-58.25	-60.99	11.64		
	% aROM	9	-68.39	-70.52	16.88	10	-72.21	-72.38	12.15	.658	.529
APDF @ 0.1	% aROM	10	-63.07	-66.29	15.61	10	-67.14	-68.58	12.07	.678	.515
APDF @ 0.5	% aROM	10	-57.48	-61.36	16.04	10	-61.46	-62.12	13.37	.207	.841
APDF @ 0.9	% aROM	10	-52.22	-56.44	16.24	10	-55.02	-55.64	14.50	-.205	.842
Avg amplitude diff	deg	9	5.29	6.16	2.48	10	6.80	8.56	4.75		
	% aROM	9	6.61	6.83	2.30	10	7.92	10.00	5.35	-2.259	.054

Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$

Table 29. Female hip kinematic results for real and simulated versions of fMISS1.

		Real				*Simulated*					
Outcome Variable		n	Median	Mean	Std. dev.	n	Median	Mean	Std. dev.	*t*	*p*
Avg max	deg	4	-2.09	-6.40	15.63	4	3.12	-.45	11.87		
	% aROM	4	.61	-4.27	25.84	4	13.51	7.77	24.29	-4.434	.021*
Avg min	deg	4	-8.18	-14.39	13.77	4	-5.09	-5.00	12.01		
	% aROM	4	-8.43	-18.32	19.97	4	-5.27	-2.69	21.68	-1.772	.174
APDF @ 0.1	% aROM	6	-4.58	-8.31	19.18	6	4.31	4.72	21.26	-2.660	.045*
APDF @ 0.5	% aROM	6	.12	-1.44	21.61	6	9.28	10.74	23.58	-2.932	.033*
APDF @ 0.9	% aROM	6	6.13	8.46	27.27	6	20.78	19.06	25.84	-4.189	.009**
Avg amplitude diff	deg	4	7.88	8.00	4.50	5	3.69	4.56	3.25		
	% aROM	4	11.98	14.07	11.37	5	6.37	10.45	9.08	.424	.700

Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$

Table 30. Female hip kinematic results for real and simulated versions of fMISS2.

		Real				*Simulated*					
Outcome Variable		n	Median	Mean	Std. dev.	n	Median	Mean	Std. dev.	*t*	*p*
Avg max	deg	8	-36.42	-31.19	17.20	9	-23.90	-24.85	10.34		
	% aROM	8	-38.56	-32.52	25.89	9	-28.25	-29.67	12.68	-.149	.886
Avg min	deg	8	-42.72	-39.16	14.53	9	-32.74	-33.79	8.66		
	% aROM	8	-45.28	-44.40	17.94	9	-41.18	-40.20	10.71	-.607	.566
APDF @ 0.1	% aROM	9	-44.42	-41.17	17.10	10	-36.04	-36.75	10.40	-.835	.428
APDF @ 0.5	% aROM	9	-42.10	-35.13	19.06	10	-29.06	-29.65	10.88	-.977	.357
APDF @ 0.9	% aROM	9	-33.00	-26.98	26.65	10	-23.86	-23.82	11.99	-.357	.730
Avg amplitude diff	deg	8	6.17	7.99	5.80	9	8.82	8.92	5.18		
	% aROM	8	7.83	11.91	11.66	9	9.13	10.52	6.05	1.060	.330

Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$

Table 31. Female hip kinematic results for real and simulated versions of fSIDE.

		Real				*Simulated*					
Outcome Variable		n	Median	Mean	Std. dev.	n	Median	Mean	Std. dev.	*t*	*p*
Avg max	deg	10	-57.28	-57.41	13.55	9	-44.08	-41.94	11.73		
	% aROM	10	-63.52	-62.88	16.88	9	-48.31	-47.60	15.68	-5.580	.001**
Avg min	deg	10	-63.73	-63.49	14.48	9	-57.45	-51.43	12.35		
	% aROM	10	-69.41	-69.43	17.61	9	-60.73	-58.02	15.55	-2.386	.044*
APDF @ 0.1	% aROM	10	-64.64	-66.09	17.66	10	-58.23	-57.04	17.33	-2.785	.021*
APDF @ 0.5	% aROM	10	-61.79	-61.31	17.38	10	-51.51	-50.85	17.29	-3.929	.003**
APDF @ 0.9	% aROM	10	-57.10	-56.20	17.25	10	-43.52	-44.11	17.37	-5.433	<.001***
Avg amplitude diff	deg	10	5.77	6.09	2.64	9	7.76	9.53	6.62		
	% aROM	10	5.94	6.57	2.70	9	7.38	10.46	6.90	-1.519	.167

Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$

Table 32. Female electromyography signal results for real and simulated versions of fQUAD1.

		Real				*Simulated*					
Outcome Variable		n	Median	Mean	Std. dev.	n	Median	Mean	Std. dev.	*t*	*p*
UES											
Max	% MVC	9	16.46	15.68	9.51	9	7.13	7.25	4.46	2.616	.031*
APDF @ 0.1	% MVC	8	1.41	1.48	.89	8	.63	.57	.22	2.937	.022*
APDF @ 0.5	% MVC	8	2.37	3.08	2.21	8	1.33	1.23	.35	2.366	.050*
APDF @ 0.9	% MVC	9	5.90	6.11	4.48	9	2.29	2.40	.98	2.702	.027*
LES											
Max	% MVC	9	7.51	9.90	5.18	7	5.91	6.52	3.10	1.948	.099
APDF @ 0.1	% MVC	8	.74	1.01	1.00	7	.52	.71	.50	-.112	.915
APDF @ 0.5	% MVC	9	1.34	1.66	1.23	7	.87	1.30	.79	.884	.411
APDF @ 0.9	% MVC	9	3.94	4.53	2.10	7	1.95	2.65	1.70	2.407	.053
LD											
Max	% MVC	10	18.74	29.79	42.69	9	16.47	31.02	35.54	.004	.997
APDF @ 0.1	% MVC	10	4.04	6.02	5.70	9	2.87	3.80	3.59	1.932	.089
APDF @ 0.5	% MVC	10	8.09	10.00	9.70	9	5.97	7.69	6.71	1.452	.185
APDF @ 0.9	% MVC	10	13.14	16.12	16.83	9	9.45	14.45	12.93	.718	.493
RA											
Max	% MVC	10	5.24	6.86	4.76	9	5.84	7.20	4.56	.021	.984
APDF @ 0.1	% MVC	10	.74	.99	.78	9	.67	1.10	1.06	-.201	.846
APDF @ 0.5	% MVC	10	1.29	1.61	1.18	9	1.14	1.99	1.86	-.531	.610
APDF @ 0.9	% MVC	10	2.34	3.01	2.32	9	2.96	3.75	2.94	-.541	.621
EO											
Max	% MVC	10	7.47	10.26	9.77	9	8.02	10.75	11.01	.089	.931
APDF @ 0.1	% MVC	9	1.49	2.47	2.35	8	1.29	1.49	1.43	2.535	.039*
APDF @ 0.5	% MVC	10	2.31	3.57	3.88	9	2.28	2.71	2.07	1.262	.242
APDF @ 0.9	% MVC	10	4.34	6.08	6.12	9	3.23	5.50	4.78	.487	.639
IO											
Max	% MVC	10	9.75	14.21	14.69	8	11.32	12.25	8.40	.707	.502
APDF @ 0.1	% MVC	10	1.62	2.43	2.01	8	1.80	1.60	.75	1.524	.171

APDF @ 0.5	% MVC	10	3.44	3.81	3.02	8	3.17	3.44	1.82	.599	.568
APDF @ 0.9	% MVC	10	5.39	6.87	6.52	8	6.28	6.82	4.26	.312	.764
GMax											
Max	% MVC	10	8.27	22.50	29.79	9	4.57	6.03	5.25	1.790	.111
APDF @ 0.1	% MVC	10	1.35	1.74	1.40	8	.37	.55	.46	3.561	.009**
APDF @ 0.5	% MVC	10	2.58	4.06	4.59	9	.74	.86	.66	2.282	.052
APDF @ 0.9	% MVC	10	4.13	8.33	10.40	9	1.26	1.93	1.94	2.198	.059
BF											
Max	% MVC	10	3.24	4.81	5.64	9	1.99	2.94	3.61	-.582	.577
APDF @ 0.1	% MVC	8	.25	.34	.37	5	.08	.29	.37	.232	.828
APDF @ 0.5	% MVC	10	.90	.94	.84	8	.37	.55	.51	.429	.681
APDF @ 0.9	% MVC	10	1.84	2.45	2.68	9	.76	1.08	.92	1.107	.301

Statistical significance is represented by the following: *p<.05, **p<.01, ***p<.001

Table 33. Female electromyography signal results for real and simulated versions of fQUAD2.

		Real				*Simulated*					
Outcome Variable		n	Median	Mean	Std. dev.	n	Median	Mean	Std. dev.	*t*	*p*
UES											
Max	% MVC	9	7.30	14.86	17.55	9	9.52	14.48	13.44	.087	.933
APDF @ 0.1	% MVC	8	1.05	1.15	.76	8	.82	1.16	1.29	1.547	.166
APDF @ 0.5	% MVC	8	2.39	2.31	.92	8	1.39	2.42	2.05	.686	.515
APDF @ 0.9	% MVC	8	4.85	6.28	4.32	8	4.52	6.27	6.04	.200	.847
LES											
Max	% MVC	10	8.70	11.58	7.92	9	9.26	12.64	9.55	-.205	.842
APDF @ 0.1	% MVC	9	.60	1.17	1.06	8	.62	1.26	1.56	-.885	.405
APDF @ 0.5	% MVC	10	1.56	2.13	1.68	8	2.09	3.30	4.00	-.879	.409
APDF @ 0.9	% MVC	10	5.22	6.43	5.51	8	6.56	8.17	6.68	-.503	.630
LD											
Max	% MVC	10	18.44	18.56	14.31	10	12.66	15.77	15.55	1.186	.266
APDF @ 0.1	% MVC	10	3.28	3.57	2.54	10	2.21	2.48	1.46	2.443	.037*
APDF @ 0.5	% MVC	10	6.11	6.57	4.41	10	4.76	5.06	3.14	2.109	.064
APDF @ 0.9	% MVC	10	10.77	11.98	10.07	10	8.21	8.86	7.28	2.264	.050*

RA											
Max	% MVC	10	4.54	7.48	6.91	10	3.38	4.95	3.67	1.186	.266
APDF @ 0.1	% MVC	10	.61	.91	.83	9	.72	.78	.55	1.230	.254
APDF @ 0.5	% MVC	10	1.04	1.49	1.30	10	.97	1.29	1.13	1.532	.160
APDF @ 0.9	% MVC	10	2.18	3.04	2.43	10	1.54	2.29	2.06	2.409	.039*
EO											
Max	% MVC	10	5.61	7.81	6.83	10	5.38	5.23	3.49	1.708	.122
APDF @ 0.1	% MVC	9	1.80	1.67	1.01	9	1.33	1.53	1.43	.301	.771
APDF @ 0.5	% MVC	10	2.48	2.36	1.54	10	1.97	2.21	2.02	.295	.775
APDF @ 0.9	% MVC	10	3.74	4.24	3.18	10	2.87	3.23	2.63	1.340	.213
IO											
Max	% MVC	9	9.32	14.58	12.06	9	12.61	12.06	6.62	.735	.483
APDF @ 0.1	% MVC	9	2.68	3.08	2.92	9	1.97	2.36	1.34	.977	.357
APDF @ 0.5	% MVC	9	3.69	5.21	4.70	9	3.93	3.92	1.81	1.074	.314
APDF @ 0.9	% MVC	9	5.23	8.40	7.38	9	5.67	6.48	3.28	.996	.349
GMax											
Max	% MVC	10	7.86	10.07	9.88	10	3.49	9.60	12.42	.141	.891
APDF @ 0.1	% MVC	10	1.42	1.48	1.02	10	.70	.81	.54	2.191	.056
APDF @ 0.5	% MVC	10	2.25	2.73	2.03	10	1.01	1.96	1.79	1.413	.191
APDF @ 0.9	% MVC	10	4.39	5.38	4.97	10	1.89	4.49	5.37	.650	.532
BF											
Max	% MVC	10	2.77	3.12	2.66	10	2.05	3.16	2.68	-.045	9.65
APDF @ 0.1	% MVC	8	.15	.54	.75	6	.15	.32	.37	1.036	.348
APDF @ 0.5	% MVC	10	.49	.99	1.20	9	.33	.67	.60	.889	.400
APDF @ 0.9	% MVC	10	1.20	1.83	1.80	10	1.04	1.27	1.12	1.141	.283

Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$

Table 34. Female electromyography signal results for real and simulated versions of fMISS1.

		Real				*Simulated*					
Outcome Variable		n	Median	Mean	Std. dev.	n	Median	Mean	Std. dev.	*t*	*p*
UES											
Max	% MVC	5	6.82	12.63	12.94	4	11.19	16.94	13.26	-1.722	.184
APDF @ 0.1	% MVC	4	.41	2.74	4.89	2	.90	1.99	2.74	.654	.631
APDF @ 0.5	% MVC	5	.49	3.96	7.56	4	2.05	3.31	4.06	.502	.650
APDF @ 0.9	% MVC	5	1.38	6.06	9.79	4	4.02	6.53	5.93	-.201	.853
LES											
Max	% MVC	6	1.80	2.89	2.89	5	4.45	6.09	3.58	-1.149	.315
APDF @ 0.1	% MVC	5	.40	.55	.61	4	.92	.94	.89	-.768	.498
APDF @ 0.5	% MVC	5	.65	.90	.91	5	.44	1.30	1.47	-.768	.498
APDF @ 0.9	% MVC	5	1.15	1.62	1.50	5	1.47	2.41	2.47	-.566	.611
LD											
Max	% MVC	6	7.31	23.66	34.76	5	7.67	14.56	16.26	.890	.424
APDF @ 0.1	% MVC	6	1.38	4.14	6.66	3	2.54	5.08	4.81	.639	.588
APDF @ 0.5	% MVC	6	2.84	7.80	11.67	5	3.56	5.60	8.08	.946	.398
APDF @ 0.9	% MVC	6	4.84	12.78	17.68	5	5.33	8.92	12.00	.962	.390
RA											
Max	% MVC	6	3.51	4.18	2.85	5	2.85	4.27	4.56	-.035	.974
APDF @ 0.1	% MVC	5	.80	.83	.18	4	.39	.42	.14	8.142	.004**
APDF @ 0.5	% MVC	6	1.47	1.23	.59	5	.83	.69	.35	3.557	.024*
APDF @ 0.9	% MVC	6	2.30	2.04	1.01	5	1.38	1.19	.59	3.043	.038*
EO											
Max	% MVC	6	11.02	10.61	8.59	5	5.25	7.51	5.59	1.994	.117
APDF @ 0.1	% MVC	5	1.71	2.73	3.11	4	.75	.80	.49	1.760	.177
APDF @ 0.5	% MVC	6	2.89	3.76	3.90	5	1.53	1.39	.87	1.905	.129
APDF @ 0.9	% MVC	6	5.14	5.59	4.87	5	3.05	3.21	2.12	1.761	.153
IO											
Max	% MVC	6	15.05	28.42	33.35	5	11.40	20.14	16.59	1.030	.361
APDF @ 0.1	% MVC	6	3.16	4.11	3.80	5	.85	.91	.57	1.820	.143

APDF @ 0.5	% MVC	6	4.87	7.45	7.95	5	2.90	2.93	2.02	1.775	.150
APDF @ 0.9	% MVC	6	7.56	14.26	15.55	5	4.88	8.36	7.14	1.342	.251
GMax											
Max	% MVC	5	13.80	20.11	22.00	4	4.03	37.83	58.67	.223	.838
APDF @ 0.1	% MVC	3	5.67	6.25	4.43	2	.13	2.44	4.70	2.144	.278
APDF @ 0.5	% MVC	5	2.64	7.66	9.29	4	.35	4.33	7.62	.935	.419
APDF @ 0.9	% MVC	5	3.97	11.73	14.25	4	.76	18.91	29.61	.179	.869
BF											
Max	% MVC	5	2.29	11.55	15.44	4	4.08	6.93	9.16	1.422	.250
APDF @ 0.1	% MVC	2	.55	1.90	2.35	1	.19	.19	.17		
APDF @ 0.5	% MVC	3	1.34	3.24	4.11	2	.61	1.06	1.38	1.443	.386
APDF @ 0.9	% MVC	5	8.23	9.08	8.52	4	.55	3.18	5.23	1.765	.176

Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$

Table 35. Female electromyography signal results for real and simulated versions of fMISS2.

		Real				*Simulated*					
Outcome Variable		n	Median	Mean	Std. dev.	n	Median	Mean	Std. dev.	*t*	*p*
UES											
Max	% MVC	7	6.48	11.29	13.41	6	6.70	10.65	9.57	.865	.427
APDF @ 0.1	% MVC	5	1.78	1.45	1.05	4	.49	.71	.83	1.856	.161
APDF @ 0.5	% MVC	5	2.43	3.35	3.03	4	1.42	1.38	.88	1.580	.212
APDF @ 0.9	% MVC	7	2.78	5.30	7.52	6	3.59	4.53	3.63	.764	.479
LES											
Max	% MVC	7	7.59	9.55	5.72	6	6.37	7.22	4.17	.233	.825
APDF @ 0.1	% MVC	7	.69	2.37	3.81	6	1.15	1.90	2.26	-1.521	.189
APDF @ 0.5	% MVC	7	1.37	2.96	3.91	6	1.52	3.01	3.39	-1.442	.209
APDF @ 0.9	% MVC	7	3.64	5.99	5.33	6	2.68	4.48	4.01	-.221	.834
LD											
Max	% MVC	8	9.63	8.85	4.72	7	7.50	7.52	5.71	.296	.777
APDF @ 0.1	% MVC	8	1.82	2.78	3.05	6	.23	.81	1.17	1.648	.160
APDF @ 0.5	% MVC	8	2.77	3.91	3.40	7	.59	1.77	2.22	1.060	.330
APDF @ 0.9	% MVC	8	4.83	5.69	3.80	7	3.83	3.57	2.78	.895	.405

RA											
Max	% MVC	8	5.83	12.22	13.37	7	5.11	13.12	21.04	1.208	.273
APDF @ 0.1	% MVC	8	.84	1.30	1.38	7	.42	.40	.29	1.920	.103
APDF @ 0.5	% MVC	8	2,25	2.57	2.28	7	.89	.87	.57	1.910	.105
APDF @ 0.9	% MVC	8	3.95	7.49	7.83	7	2.12	5.37	8.74	1.605	.160
EO											
Max	% MVC	8	5.82	11.07	11.22	7	4.34	7.22	9.13	1.926	.102
APDF @ 0.1	% MVC	7	1.80	2.47	1.83	6	.72	1.18	1.12	1.906	.115
APDF @ 0.5	% MVC	8	1.96	3.63	3.78	7	1.21	1.90	1.75	1.696	.141
APDF @ 0.9	% MVC	8	3.70	7.36	7.94	7	1.45	3.79	5.45	2.073	.084
IO											
Max	% MVC	8	21.83	30.44	26.18	6	9.14	14.62	12.92	1.803	.131
APDF @ 0.1	% MVC	8	3.06	4.83	4.08	6	1.07	1.94	2.16	1.576	.176
APDF @ 0.5	% MVC	8	7.45	7.64	5.64	6	2.19	3.36	3.06	1.580	.175
APDF @ 0.9	% MVC	8	13.21	16.93	15.06	6	5.29	7.99	8.19	1.901	.116
GMax											
Max	% MVC	8	11.93	34.49	41.92	7	8.23	22.62	26.99	1.997	.093
APDF @ 0.1	% MVC	7	1.24	4.33	7.64	5	.47	1.95	3.75	1.097	.334
APDF @ 0.5	% MVC	8	3.62	8.62	14.98	7	1.52	3.73	6.70	1.318	.235
APDF @ 0.9	% MVC	8	5.44	19.92	27.51	7	3.95	12.04	16.29	1.651	.150
BF											
Max	% MVC	8	5.10	7.04	5.82	7	3.80	5.03	4.24	.642	.544
APDF @ 0.1	% MVC	7	.45	2.31	4.35	5	.46	.70	.73	.490	.650
APDF @ 0.5	% MVC	8	1.17	2.73	4.40	7	.98	1.66	1.23	-1.209	.272
APDF @ 0.9	% MVC	8	2.41	4.47	4.90	7	1.80	2.93	2.54	.306	.770

Statistical significance is represented by the following: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$

Table 36. Female electromyography signal results for real and simulated versions of fSIDE.

		Real				*Simulated*					
Outcome Variable		n	Median	Mean	Std. dev.	n	Median	Mean	Std. dev.	*t*	*p*
UES											
Max	% MVC	8	32.59	30.27	19.59	8	13.91	20.83	16.59	1.600	.154
APDF @ 0.1	% MVC	7	3.73	3.83	3.53	7	1.17	2.89	3.55	1.862	.112
APDF @ 0.5	% MVC	8	7.59	7.70	5.37	7	3.50	5.41	5.56	1.738	.133
APDF @ 0.9	% MVC	8	18.26	16.31	10.12	7	7.84	10.97	7.98	1.624	.156
LES											
Max	% MVC	8	20.03	19.10	12.28	8	15.98	14.36	10.67	1.879	.102
APDF @ 0.1	% MVC	8	.67	1.99	3.04	7	.36	.91	1.07	1.451	.197
APDF @ 0.5	% MVC	8	3.78	4.74	5.52	8	1.93	2.64	3.05	2.005	.085
APDF @ 0.9	% MVC	8	8.12	10.31	8.89	8	7.37	7.74	7.35	1.800	.115
LD											
Max	% MVC	9	17.36	30.39	25.84	9	12.04	17.09	11.74	1.902	.094
APDF @ 0.1	% MVC	9	4.31	4.29	2.35	9	1.32	2.07	1.87	4.044	.004**
APDF @ 0.5	% MVC	9	6.83	8.93	6.61	9	3.30	4.07	2.90	3.349	.010*
APDF @ 0.9	% MVC	9	9.82	16.46	14.16	9	6.14	8.46	5.60	2.166	.062
RA											
Max	% MVC	9	5.67	6.80	5.67	9	4.29	4.45	2.18	.986	.353
APDF @ 0.1	% MVC	9	.94	1.08	.76	9	.56	.52	.29	2.524	.036*
APDF @ 0.5	% MVC	9	1.76	1.90	1.31	9	1.04	1.02	.54	1.939	.088
APDF @ 0.9	% MVC	9	3.20	3.85	3.28	9	1.91	2.05	1.29	1.410	.196
EO											
Max	% MVC	9	20.88	21.09	15.88	9	8.60	12.43	12.66	1.635	.141
APDF @ 0.1	% MVC	9	2.35	2.36	1.76	8	.59	1.16	1.33	1.982	.088
APDF @ 0.5	% MVC	9	5.90	5.42	3.76	9	1.27	2.21	2.77	2.155	.063
APDF @ 0.9	% MVC	9	12.81	10.24	6.79	9	2.93	5.17	5.95	1.785	.112
IO											
Max	% MVC	9	18.82	20.09	14.26	9	6.75	12.76	12.40	1.306	.228
APDF @ 0.1	% MVC	9	2.12	2.57	2.45	8	.75	2.04	2.74	.340	.744

APDF @ 0.5	% MVC	9	5.16	5.62	5.16	9	1.81	3.51	4.61	1.102	.302
APDF @ 0.9	% MVC	9	10.75	10.40	8.47	9	3.25	6.24	7.24	1.386	.203
GMax											
Max	% MVC	9	8.53	12.46	16.07	9	5.80	8.02	6.21	.935	.377
APDF @ 0.1	% MVC	8	1.30	1.29	1.27	8	.49	.87	.79	1.824	.111
APDF @ 0.5	% MVC	9	2.37	2.33	2.33	9	1.04	1.88	1.66	.788	.454
APDF @ 0.9	% MVC	9	5.30	5.51	5.30	9	2.86	4.11	3.49	1.004	.345
BF											
Max	% MVC	9	2.16	2.48	2.15	9	2.51	2.28	1.21	.004	.997
APDF @ 0.1	% MVC	7	.28	.48	.62	6	.09	.13	.14	1.734	.143
APDF @ 0.5	% MVC	9	.52	.71	.92	8	.22	.26	.23	1.748	.124
APDF @ 0.9	% MVC	9	.84	1.21	1.33	9	.61	.70	.53	1.191	.268