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# Manual material handling in the supermarket sector. Part 1: Joint angles and muscle activity of trapezius descendens and erector spinae longissimus

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ABSTRACT

Work-related musculoskeletal disorders are highly prevalent in the supermarket sector with manual material handling being one of the most commonly identified occupational risk factors. This cross-sectional study applied inertial motion capture and electromyography (EMG) to measure full-body kinematics and muscle activity of trapezius descendens and erector spinae longissimus during 50 manual material handling tasks performed by 17 workers in two supermarkets. The handling of bread and cucumbers to high shelf heights showed the highest trapezius muscle activity (from 47% to 59% peak normalized EMG), while the handling of bananas as well as lifting milk, bread and cucumbers from low to high positions showed the highest erector spinae activity (from 59% to 71%). Twenty-two tasks involved flexing the shoulders and trunk more than 90° and 50°, respectively. Based on these results, several manual handling practices in supermarkets should be reconsidered to reduce the physical work demands.

## 1. Introduction

Work-related musculoskeletal disorders (WRMD) are multifactorial in nature and are associated with physical, psychosocial and individual factors (Waters, 2001; Hernandez et al., 2012), which is one of several reasons why it has been difficult to achieve a clear scientific consensus on causality. However, some of the most well-documented associations to WRMD are ergonomic job exposures involving strenuous physical work tasks (Punnett and Wegman, 2004; da Costa and Vieira, 2010; van Rijn et al., 2009), manual material handling (MMH) or lifting (Punnett and Wegman, 2004; da Costa and Vieira, 2010; Cole and Grimshaw, 2003; Coenen et al., 2014; Fernandes et al., 2016; Fransen et al., 2011; Reid et al., 2010; Van Rijn et al., 2010; Mayer et al., 2012; Van Rijn et al., 2009), working with arms above shoulder height (Van Rijn et al., 2010; Mayer et al., 2012; Svendsen et al., 2004; NIOSH, 1998), awkward postures (da Costa and Vieira, 2010; Fernandes et al., 2016; Fransen et al., 2011; Reid et al., 2010; NIOSH, 1998) and repetitive work (Punnett and Wegman, 2004; da Costa and Vieira, 2010; van Rijn et al., 2009; Van Rijn et al., 2009; NIOSH, 1998). In particular, causal association between MMH and low back pain has been established (Punnett and Wegman, 2004; da Costa and Vieira, 2010; Cole and Grimshaw, 2003; Coenen et al., 2014; Fernandes et al., 2016; NIOSH, 1998; Burdorf and Sorock, 1997; Hoogendoorn et al., 1999; Lötters et al., 2003), although some controversy have arisen in recent years due to a number of highly debated conflicting findings (Swain et al., 2020).

MMH is prevalent in many industries, such as construction, transportation and retail (Heran-Le Roy et al., 1999). Among these industries, the supermarket or grocery sector (i.e. supermarkets, hypermarkets, convenience stores etc.), which is typically included under the umbrella category "retail", have received little attention in the scientific literature. However, in the few studies that have attempted to determine the prevalence of WRMD in the grocery sector, the results are concerning (Ryan, 1989; Porter et al., 1991; Campany and Personick, 1992; Guo et al., 1999; Clarke, 2003; Violante et al., 2005; Forcier et al., 2008; Silva et al., 2015; Anton and Weeks, 2016). For example, Forcier et al. (2008) found that in a one-year period, 131 supermarket workers reported 140 musculoskeletal injuries, accounting for 63% of all compensable

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**Abbreviations**

| | |
|---|---|
| WRMD | Work-related musculoskeletal disorders |
| MMH | Manual material handling |
| sEMG | Surface electromyography |
| FV | Fruit and vegetables |
| BR | Bread |
| MD | Meat and dairy |
| CO | Colonial |
| H | Shelf height |
| D | Shelf depth |
| SP | Starting position |
| MVIC | Maximal voluntary isometric contraction |
| IMC | Inertial motion capture |
| ROM | Range-of-motion |
| nEMG | Normalized electromyography |

occupational injuries and 73% of days away from work. The most affected body regions were the lower back (37%), shoulders (16%) and wrists (9%). More recently, Anton and Weeks (2016) found that 78% of supermarket workers reported musculoskeletal symptoms in at least one body region during a 12-month period. Again, the low back was the most frequent affected body region (51%), followed by the feet (50%), wrist/hand (31%) and shoulders (31%).

Due to the high prevalence of WRMD in the industry, there has been some effort to determine the causal pathway from exposure to WRMD as well as to evaluate the efficacy of ergonomic interventions, much of which have targeted the cashiers and checkstands (Johansson et al., 1998; Lehman et al., 2001; Rodacki et al., 2006; Draicchio et al., 2012). However, the majority of supermarket workers are primarily engaged in the receiving, stocking and re-arranging of groceries. For this subgroup of workers, not much is known about the physical efforts required to perform their daily work (St-Vincent et al., 2005; Silvetti et al., 2015). Only two studies have applied detailed biomechanical measurements (e.g. surface electromyography (sEMG) and motion analysis) to analyze stocking activities in a supermarket context; Silvetti et al. (2015) found that shelf height had a significant influence on the muscular effort required during load handling in a laboratory setting. Balogh et al. (2016) used sEMG and triaxial accelerometers to measure neck and forearm muscle activities and posture on 22 female supermarket workers in the field. The study showed that stocking groceries (referred to as picking work) showed the highest muscular loads compared with cashier, delicatessen or mixed work, but only provided an overall estimate of the muscular demands, which prevents the identification of potentially hazardous handling tasks. Hence, there is an urgent need for identifying hazardous exposures during MMH in the supermarket sector based on procedures that closely reflect actual working conditions.

In this two-part study, we analyzed working postures, muscular demands and biomechanical loads during a wide range of MMH tasks in the Danish supermarket sector to an extent and level of detail that is unprecedented in the scientific literature. To achieve this, we employed the newest available technology for full-body inertial-based motion analysis and musculoskeletal modelling, as well as sEMG measurements, to analyze kinematic, kinetic and muscle activity data during common MMH tasks performed at the workplace. The present paper reports joint angles for the shoulders, trunk and knees as well as muscle activities for trapezius descendens and erector spinae longissimus, while the second paper reports the kinetic results from the musculoskeletal modelling. These data will provide new insight into the physical efforts required by supermarket workers and help identify MMH tasks that pose a risk for WRMD in the industry.

## 2. Material and methods

### 2.1. Subjects

This two-part cross-sectional study included 17 healthy full-time (min. 30 h/week) workers from two stores of a major Danish supermarket chain (8 male and 9 female, age: 27.6 ± 8.5 years, height: 174.4 ± 9.1 cm, mass: 76.6 ± 14.7 kg, experience: 9.4 ± 7.4 years, h/week: 37.6 ± 6.3). All recruited subjects had at least 3 months of work experience at the company and no musculoskeletal injury or progressive diseases at the time of data collection. A collaboration agreement was formulated with the senior human resources specialist of the company who subsequently contacted a number of store managers in the North Jutland region of Denmark. Two managers agreed to involve their stores from which employees volunteered, including the store managers themselves, after being informed about the purpose and methods of the study. The subjects were given their usual salary by the company for the time allocated to the study, but did not receive any additional personal financial compensation. All subjects provided written informed consent before data collection was undertaken and the study followed the ethical guidelines of The North Denmark Region Committee on Health Research Ethics. All data were collected in October 2018.

### 2.2. Data collection

The MMH tasks could roughly be subdivided into the following categories: 1) Fruit and vegetables (FV), 2) bread (BR), 3) meat and dairy (MD) and 4) colonial (CO), i.e. edible and non-edible goods with long shelf lives. The stores were not divided into departments with its own affiliated workers, as most larger supermarkets or hypermarkets would. Hence, the workers would typically stock goods in all the aforementioned categories on any given day.

Based on observations made in similar stores in the months preceding data collection as well as conversations with employees, store managers and the senior human resources specialist, a subset of MMH tasks spanning all the categories were selected for further analysis (see Tables 1a and 1b). The tasks were chosen based on factors such as frequency of lifts, weight and ease-of-handling. Furthermore, as most of the merchandise could be placed on several shelf heights (H) with varying shelf depth (D) and from different starting positions (SP), multiple scenarios with different start and end positions were included in the analysis, indicated with the numbers 1–4 (low to high or closest to farthest). However, not all merchandise were placed on all shelf heights: for example, bananas were only placed on low shelves as this was the common procedure in the stores. Finally, for the bread category, two scenarios were included: one where the box was placed on the shelf with two hands (BR1) and another where the subjects were allowed to place the box on the edge of the shelf and push it into place with either one or two hands (BR2). During all tasks, the subjects were informed about the start and end position, but were otherwise encouraged to handle the merchandise as they normally would. However, for the two-handed tasks without handles, they were asked to place and keep their hands on either side of the merchandise, at approximately 1/3 of the boxes' length. If the boxes had handles, they were instructed to use them. For the one-handed lifts, they were asked to use their right hand only and place it at the center of the merchandise. These restrictions were included so the hand placement would be consistent between lifts and subjects to facilitate the modelling of the hand-box interaction in the musculoskeletal model analysis (described in part 2) and reduce intra- and inter-subject variability to some extent. In total, 50 different MMH tasks were included in the analysis with the subjects performing four consecutive repetitions of each task. The MMH categories as well as the tasks within each category were counterbalanced to avoid any order effects.

The experimental procedures were as follows: first, the measurement equipment was set up in a small break room, where the subjects were

**Table 1a**
Abbreviations and description of the selected manual material handling tasks, including the merchandise handled, whether the subject used 1 or 2 hands, starting position above floor level, shelf height, shelf depth, weight and dimensions (length (L) x width (W) x height (H)). Note that there are two listed shelf heights and depths, corresponding to the first and second store where data were collected.

| Abbreviation (tables) | Abbreviation (text) | Merchandise | 1 or 2 hands | Starting position (cm) | Shelf height (cm) | Depth (cm) | Mass (kg) | Dimensions (L x W x H) |
|---|---|---|---|---|---|---|---|---|
| BR1-SP1-H1 | Bread-LowToLow | 8 rye bread | 2 | 15 | 16.5 18.5 | – – | 7.9 | 59 × 40 × 14 |
| BR1-SP1-H2 | Bread-LowToMid | 8 rye bread | 2 | 15 | 81.5 80 | – – | 7.9 | 59 × 40 × 14 |
| BR1-SP1-H3 | Bread-LowToHigh | 8 rye bread | 2 | 15 | 146.5 144.5 | – – | 7.9 | 59 × 40 × 14 |
| BR1-SP2-H1 | Bread-HighToLow | 8 rye bread | 2 | 71 | 16.5 18.5 | – – | 7.9 | 59 × 40 × 14 |
| BR1-SP2-H2 | Bread-HighToMid | 8 rye bread | 2 | 71 | 81.5 80 | – – | 7.9 | 59 × 40 × 14 |
| BR1-SP2-H3 | Bread-HighToHigh | 8 rye bread | 2 | 71 | 146.5 144.5 | – – | 7.9 | 59 × 40 × 14 |
| BR2-SP2-H2 | Bread-v2-HighToMid | 8 rye bread | 2 | 71 | 81.5 80 | – – | 7.9 | 59 × 40 × 14 |
| BR2-SP2-H3 | Bread-v2-HighToHigh | 8 rye bread | 2 | 71 | 146.5 144.5 | – – | 7.9 | 59 × 40 × 14 |
| FV1–SP1–H1 | Bananas-LowToLow | 100 bananas | 2 | 15 | 46.5 41 | – – | 20.2 | 52 × 39 × 20 |
| FV1–SP2–H1 | Bananas-HighToLow | 100 bananas | 2 | 71 | 46.5 41 | – – | 20.2 | 52 × 39 × 20 |
| FV2–SP1–H2 | Salads-LowToMid | 10 green salads | 2 | 15 | 86 68 | – – | 5.3 | 59 × 38.5 × 15.5 |
| FV2–SP1–H3 | Salads-LowToHigh | 10 green salads | 2 | 15 | 140.5 108 | – – | 5.3 | 59 × 38.5 × 15.5 |
| FV2–SP2–H2 | Salads-HighToMid | 10 green salads | 2 | 71 | 86 68 | – – | 5.3 | 59 × 38.5 × 15.5 |
| FV2–SP2–H3 | Salads-HighToHigh | 10 green salads | 2 | 71 | 140.5 108 | – – | 5.3 | 59 × 38.5 × 15.5 |
| FV3–SP1–H2 | Cucumbers-LowToMid | 30 cucumbers | 2 | 15 | 86 68 | – – | 10.2 | 59 × 38.5 × 15.5 |
| FV3–SP1–H3 | Cucumbers-LowToHigh | 30 cucumbers | 2 | 15 | 140.5 108 | – – | 10.2 | 59 × 38.5 × 15.5 |
| FV3–SP2–H2 | Cucumbers-HighToMid | 30 cucumbers | 2 | 71 | 86 68 | – – | 10.2 | 59 × 38.5 × 15.5 |
| FV3–SP2–H3 | Cucumbers-HighToHigh | 30 cucumbers | 2 | 71 | 140.5 108 | – – | 10.2 | 59 × 38.5 × 15.5 |
| FV4–SP1–H4 | Herbs-LowToHigh | Bundle of fresh herbs | 2 | 15 | 156.5 151.5 | – – | 1 | 18.5 × 13 × 29 |
| FV4–SP2–H4 | Herbs-HighToHigh | Bundle of fresh herbs | 2 | 71 | 156.5 151.5 | – – | 1 | 18.5 × 13 × 29 |
| CO1–SP1–H1 | TomatoCans-LowToLow | 12 cans of tomatoes | 2 | 15 | 16.5 18.5 | – – | 5.6 | 30 × 22.5 × 11 |
| CO1–SP1–H2 | TomatoCans-LowToMid | 12 cans of tomatoes | 2 | 15 | 78 80 | – – | 5.6 | 30 × 22.5 × 11 |
| CO1–SP2–H1 | TomatoCans-HighToLow | 12 cans of tomatoes | 2 | 71 | 16.5 18.5 | – – | 5.6 | 30 × 22.5 × 11 |
| CO1–SP2–H2 | TomatoCans-HighToMid | 12 cans of tomatoes | 2 | 71 | 78 80 | – – | 5.6 | 30 × 22.5 × 11 |
| CO2–SP2–H1 | VegetableOil-HighToLow | 1 vegetable oil | 1 | 71 | 16.5 18.5 | – – | 1 | 27 × 8 |
| CO2–SP2–H2 | VegetableOil-HighToMid | 1 vegetable oil | 1 | 71 | 78 80 | – – | 1 | 27 × 8 |
| CO2–SP2–H3 | VegetableOil-HighToHigh | 1 vegetable oil | 1 | 71 | 163.5 164.5 | – – | 1 | 27 × 8 |

received, informed about the procedures, given the opportunity to ask questions and filled out the consent form. Second, body mass and body dimensions were measured with a scale and caliper, respectively, where after the measurement equipment was instrumented on the subjects and maximal voluntary isometric contractions (MVIC) were performed (see section 2.2.1). Third, two investigators (SS and RB) accompanied the subject in to the shopping area with all the merchandise assembled in a transport cage with two shelves (SP1/Low and SP2/High) and the wireless receivers for the measurement systems (see section 2.2.1 and 2.2.2), a laptop computer and a video camera positioned on a rolling table (Fig. 1). The transport cage was the typical assistive device used during stocking with the selected shelf heights closely corresponding to the top and bottom of a filled pallet. The handling procedures for selected tasks are illustrated in Fig. 2 and Fig. 3.

### 2.3. sEMG measurements

sEMG was recorded bilaterally from trapezius descendens and erector spinae longissimus. Before placing the electrodes (Ambu A/S, Ballerup, Denmark), the skin was shaved and cleaned with scrubbing gel (Meditec, Parma, Italy). The electrodes were placed on the belly of the muscles, longitudinally to the muscle fibers, at the midpoint between the acromion and C7 vertebrae for trapezius descendens and at 2-finger widths lateral from the spinous process of L1 for erector spinae longissimus, according to the SENIAM recommendations (Hermens et al., 2000). A Neuroline 720 01-K bipolar sEMG configuration (Medicotest A/S, Ølstykke, Denmark) with an interelectrode distance of 2 cm was used. The sEMG-signals were pre-amplified (gain: 400) and transmitted in real-time through wireless probes to a TeleMyo DTS Telemetry 16-channel PC-interface receiver (Noraxon, Scottsdale, AZ, USA) with a sampling rate of 1500 Hz, a bandwidth of 10–500 Hz and a common mode rejection ratio better than 100 dB. The electrodes and wireless probes were fixed with Fixomull stretch tape (BSN Medical, Hamburg, DE).

MVICs were performed for both muscle groups before and after completing the experimental protocol: for trapezius, the subjects were standing with their shoulders abducted 90° and were asked to further abduct their shoulders as much as they could, while the investigators were holding on to each arm and applying downward pressure to restrict the upward motion. For erector spinae, the subjects were lying face down on a custom-built padded board with their feet fixated in a foot strap and hips supported by the edge of the board. The board had an approximately 10° slope, so the subjects' upper body was elevated above the floor and their hips slightly flexed, which enabled their upper body to hang freely parallel to the floor. From this position, the subjects were asked to extend their back as much as possible, while an investigator was standing above them, pushing down on their upper back with both hands placed between the subjects' shoulder blades. After familiarizing the subjects to the exercises, which simultaneously acted as a brief warm-up, the MVICs were performed: the subjects were instructed to gradually exert force until they reached maximal tension within a time span of 5 s and were given at least 30 s of rest between trials. Strong verbal encouragement was given throughout each trial. In total, 6 MVICs were completed for each muscle, 3 before and after the experimental protocol, of which the highest measured muscle activity was used for sEMG normalization.

### 2.4. Inertial motion capture

Full-body kinematics were measured using the Xsens MVN Awinda wireless motion-tracker (Xsens Technologies BV, Enschede, The Netherlands), which consists of 17 inertial measurement units (IMUs), sampling at 60 Hz. The IMUs were attached to the subjects with the accompanying velcro straps, headband and a tight-fitting customized t-shirt on the following body segments: one on each foot, shank, thigh, shoulders, upper arm, wrist (lower arm) and hand, as well as one placed on the pelvis, sternum and head. As described in Paulich et al. (2018), each IMU contains a 3D accelerometer, gyroscope and magnetometer, as well as a barometer and thermometer, and transmits data wirelessly to a master receiver in real-time. The inertial motion capture (IMC) system incorporates a sensor fusion algorithm as well as a reprocessing tool in the related software, Xsens MVN Analyze (v. 2019.0.0), which corrects

**Table 1b**
Abbreviations and description of the selected manual material handling tasks, including the merchandise handled, whether the subject used 1 or 2 hands, the starting position above floor level, shelf height, shelf depth, weight and dimensions (length (L) x width (W) x height (H)). Note that there are two listed shelf heights and depths, corresponding to the first and second store where data were collected.

| Abbreviation (tables) | Abbreviation (text) | Merchandise | 1 or 2 hands | Starting position (cm) | Shelf height (cm) | | Depth (cm) | | Mass (kg) | Dimensions (L x W x H) |
|---|---|---|---|---|---|---|---|---|---|---|
| MD1-SP2-H1-D1 | MincedBeef-HighToLowNear | 500 g of minced beef | 1 | 71 | 52.5 | 51 | 11 | 13 | 0.5 | 19 × 14 × 5.5 |
| MD1-SP2-H1-D2 | MincedBeef-HighToLowFar | 500 g of minced beef | 1 | 71 | 52.5 | 51 | 71 | 61 | 0.5 | 19 × 14 × 5.5 |
| MD2-SP1-H1-D1 | ColdCuts-LowToLowNear | 15 × 100 g of cold cuts | 2 | 15 | 34.5 | 30 | 15.5 | 15.5 | 2.1 | 27.5 × 13 × 17 |
| MD2-SP1-H2-D1 | ColdCuts-LowToMidNear | 15 × 100 g of cold cuts | 2 | 15 | 104.5 | 105 | 37 | 36.5 | 2.1 | 27.5 × 13 × 17 |
| MD2-SP1-H3-D1 | ColdCuts-LowToHighNear | 15 × 100 g of cold cuts | 2 | 15 | 166.5 | 159 | 37 | 36.5 | 2.1 | 27.5 × 13 × 17 |
| MD2-SP2-H1-D1 | ColdCuts-HighToLowNear | 15 × 100 g of cold cuts | 2 | 71 | 34.5 | 30 | 15.5 | 15.5 | 2.1 | 27.5 × 13 × 17 |
| MD2-SP2-H2-D1 | ColdCuts- HighToMidNear | 15 × 100 g of cold cuts | 2 | 71 | 104.5 | 105 | 37 | 36.5 | 2.1 | 27.5 × 13 × 17 |
| MD2-SP2-H3-D1 | ColdCuts-HighToHighNear | 15 × 100 g of cold cuts | 2 | 71 | 166.5 | 159 | 37 | 36.5 | 2.1 | 27.5 × 13 × 17 |
| MD2-SP2-H1-D2 | ColdCuts-HighToLowFar | 15 × 100 g of cold cuts | 2 | 71 | 34.5 | 30 | 47.5 | 59 | 2.1 | 27.5 × 13 × 17 |
| MD2-SP2-H2-D2 | ColdCuts- HighToMidFar | 15 × 100 g of cold cuts | 2 | 71 | 104.5 | 105 | 97 | 97.5 | 2.1 | 27.5 × 13 × 17 |
| MD2-SP2-H3-D2 | ColdCuts-HighToHighFar | 15 × 100 g of cold cuts | 2 | 71 | 166.5 | 159 | 97 | 97.5 | 2.1 | 27.5 × 13 × 17 |
| MD3-SP1-H1 | Milk-LowToLow | 15 × 1 L milk | 2 | 15 | 13.5 | 13.5 | – | – | 17.3 | 40 × 30 × 26 |
| MD3-SP1-H2 | Milk-LowToMid | 15 × 1 L milk | 2 | 15 | 38.5 | 38.5 | – | – | 17.3 | 40 × 30 × 26 |
| MD3-SP1-H3 | Milk-LowToHigh | 15 × 1 L milk | 2 | 15 | 64 | 64 | – | – | 17.3 | 40 × 30 × 26 |
| MD3-SP2-H1 | Milk-HighToLow | 15 × 1 L milk | 2 | 71 | 13.5 | 13.5 | – | – | 17.3 | 40 × 30 × 26 |
| MD3-SP2-H2 | Milk-HighToMid | 15 × 1 L milk | 2 | 71 | 38.5 | 38.5 | – | – | 17.3 | 40 × 30 × 26 |
| MD3-SP2-H3 | Milk-HighToHigh | 15 × 1 L milk | 2 | 71 | 64 | 64 | – | – | 17.3 | 40 × 30 × 26 |
| MD4-SP1-H1 | Yoghurts-LowToLow | 6 × 1 L yoghurts | 2 | 15 | 117.5 | 110 | – | – | 6.3 | 23 × 15.5 × 29 |
| MD4-SP1-H2 | Yoghurts-LowToHigh | 6 × 1 L yoghurts | 2 | 15 | 168 | 161 | – | – | 6.3 | 23 × 15.5 × 29 |
| MD4-SP2-H1 | Yoghurts-HighToLow | 6 × 1 L yoghurts | 2 | 71 | 117.5 | 110 | – | – | 6.3 | 23 × 15.5 × 29 |
| MD4-SP2-H2 | Yoghurts-HighToHigh | 6 × 1 L yoghurts | 2 | 71 | 168 | 161 | – | – | 6.3 | 23 × 15.5 × 29 |
| MD5-SP2-H1 | SingleYoghurt-HighToLow | 1 × 1 L yoghurt | 1 | 71 | 148 | 110 | – | – | 1.1 | 23 × 7 |
| MD5-SP2-H2 | SingleYoghurt-HighToHigh | 1 × 1 L yoghurt | 1 | 71 | 174 | 161 | – | – | 1.1 | 23 × 7 |

for orientation drift and improves the consistency of the position and orientation estimates. The data from the IMUs is used to drive a 23 segment kinematic model, providing joint angles fairly consistent with the standards outlined by the International Society of Biomechanics (Wu et al., 2002, 2005). Further details can be found in the Xsens MVN User Manual (Xsens Technologies B.V., 2020).

To initialize the hardware and determine the baseline estimate of the body segments' positions and orientations, a calibration procedure must be performed, which involves the subject standing in an upright neutral posture for a few seconds, then walking a few steps forward and back to the starting position. This procedure was performed before each series of tasks related to the MMH categories, e.g. all the tasks performed for fruit and vegetables.

### 2.5. Data analysis

The raw sEMG-signals obtained during the MMH tasks and MVICs were digitally filtered using a zero-phase, Butterworth fourth-order high-pass filter with a cut-off frequency of 10 Hz (De Luca et al., 2010) and a moving root-mean-square filter of 500 ms. The raw and filtered signals were plotted over the trial duration for each muscle separately and visually inspected to identify any abnormalities and assess whether the filters had successfully removed noise and artifacts. If any artifacts or signal quality issues (e.g. low signal-to-noise ratio, flat-lining or large spikes) were identified, the data for the specific muscle was discarded, while the data for the remaining muscles were included in the analysis. After the initial processing and inspections, the

**Fig. 1.** Left: rolling table with laptop computer, wireless receivers and video camera, and transport cage with shelves. Right: calibration of the motion analysis system before a measurement. The EMG electrodes are hidden under the t-shirt.

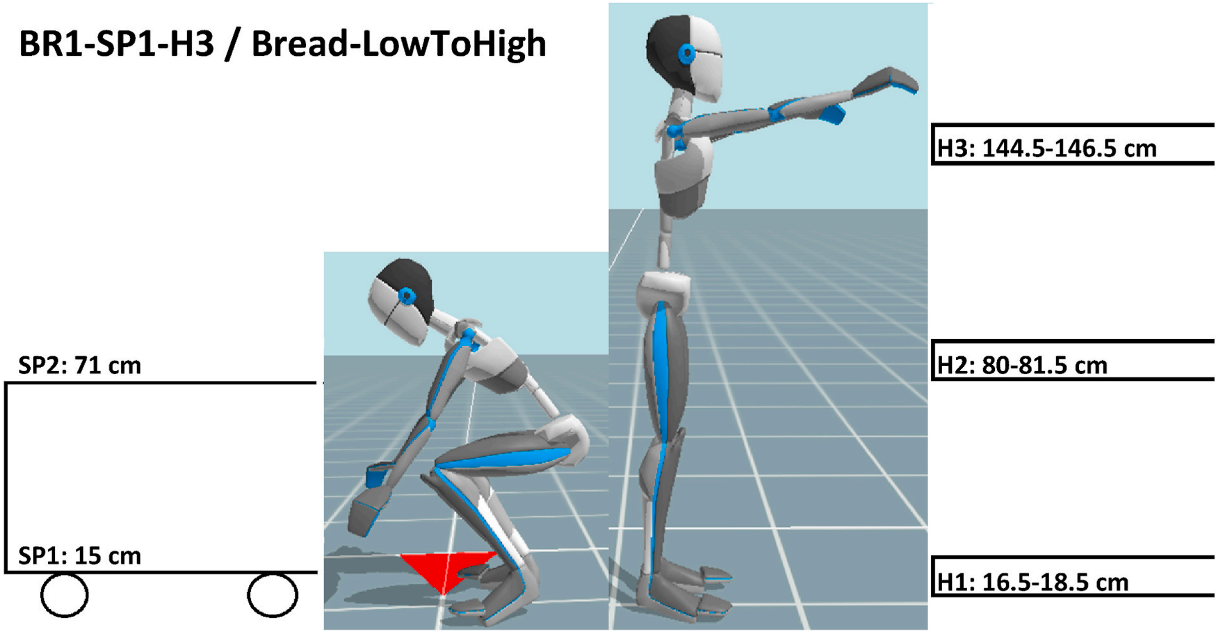


**Fig. 2.** Illustration of the starting positions and shelf heights during BR1-SP1-H3/Bread-LowToHigh. Note that the reaching distance is not depicted accurately, as the workers had to reach in over the shelves to lift or place the merchandise.

peak root-mean-square sEMG amplitude for each muscle was calculated for each repetition of the MMH tasks and normalized to the absolute maximum sEMG amplitude (nEMG) of the MVICs.

The kinematic data from the IMC system were resampled to 101 data points (one lifting cycle) for illustrative purposes, but otherwise analyzed without further processing. The start and end point of the MMH tasks were determined through visually inspecting the video recordings and defined as the first instance the subject initiated the lift with a secure grip on the handled merchandise and the instance the merchandise was securely placed on the shelf, respectively.

From the sEMG data, the peak, 90th and 50th percentile nEMG for the left and right trapezius and erector spinae were selected for further analysis. From the kinematic data, the following variables were selected: trunk forward flexion (T8 relative to the pelvis), lateral bending and rotation peak angle and range-of-motion (ROM), as well as bilateral knee and shoulder flexion peak angles and ROM.

### 2.6. Statistical analysis

Repeated measures linear mixed models (Proc Mixed, SAS) were used to test if any differences existed between the MMH tasks for the selected outcome variables, specifically the peak joint angles, ROMs and peak nEMG. The MMH tasks were included as fixed effects and subjects as random effects. The purpose of this approach was to determine least square mean estimates with 95% confidence intervals. Based on these estimates, the tasks were ranked from highest to lowest for each outcome variable to facilitate the risk assessment. While the procedure also provides differences of least square means, we did not use the many pairwise comparisons (a total of 29,400 comparisons) to avoid the risk of statistical type I errors, but rather compared the different conditions based on the ranking of the least square means and confidence intervals. Residual diagnostics plots were inspected to ensure a normal distribution of the residuals as well as homogeneity of variance, while within-subject correlation was assumed. The covariance structure was set to Variance Components, while the model was fit using restricted maximum likelihood estimation (REML). The results are presented as least square means with 95% confidence intervals based on a Satterwaite approximation. All statistical analyses were performed in SAS v. 9.4 (SAS Institute Inc., Cary, NC, USA).

## 3. Results

Of the 17 subjects from which data were collected, 15 were included in the final analysis. One subject was excluded due to systematic error in the measured sEMG data stemming mainly from wireless interference in the first store, while another was excluded as incorrect body dimensions were used during the IMC measurements. From the 15 remaining subjects, a total of 2922 IMC trials were included in the analysis, while 2672, 2774, 2611 and 2727 trials were used to analyze the muscle activities of the left and right trapezius and erector spinae, respectively. The majority of the excluded sEMG data were due to poor skin-electrode contact, leading to very low signal amplitude, large gaps and a few extreme measurements, where the filter had not successfully cut large spikes in the signal. Diagnostics plots illustrating marginal and conditional residuals were also inspected to identify extreme measurements, which were excluded if they were found to be associated with errors. Lastly, we introduced a cut-off value of 150% of MVIC, which resulted in the exclusion of 12 measurements. For the IMC data, a total of 78 trials were either missing or excluded: 32 trials were missing as the task FV2 and FV3 were not placed on both shelves for subject 2 and 3, and 16 trials missing as FV3 was not lifted from both starting positions for subject 12 and 17. An additional 5 trials of the tasks BR1 and MD2 were missing for subject 2. Sixteen trials were excluded for subject 17 as the wrong hand was used during two of the one-handed lifts (MD1 and MD5), 4 trials excluded due to errors in the kinematic data, mostly stemming from an IMU having changed position during the measurement, while 5 trials were excluded due to extreme values attributed to errors in the system's calculation of a joint angle.

The results of the linear mixed model analyses showed significant differences for the fixed effect (i.e. the MMH tasks) for all outcome variables ($p < 0.001$). The least square means with 95% confidence intervals are listed in Tables 2–4 for peak nEMG, knee and shoulder peak flexion angle, trunk peak flexion/extension and rotation angles as well as ROM, respectively, where the 25 MMH tasks with the highest values for each selected variable are ranked from highest to lowest. nEMG is presented as percentage of MVIC, while the peak joint angles and ROMs are presented in degrees. The results for the remaining variables (90th and 50th percentile nEMG, knee and shoulder flexion-extension ROM, and trunk lateral bending peak angle and ROM) and MMH tasks as well

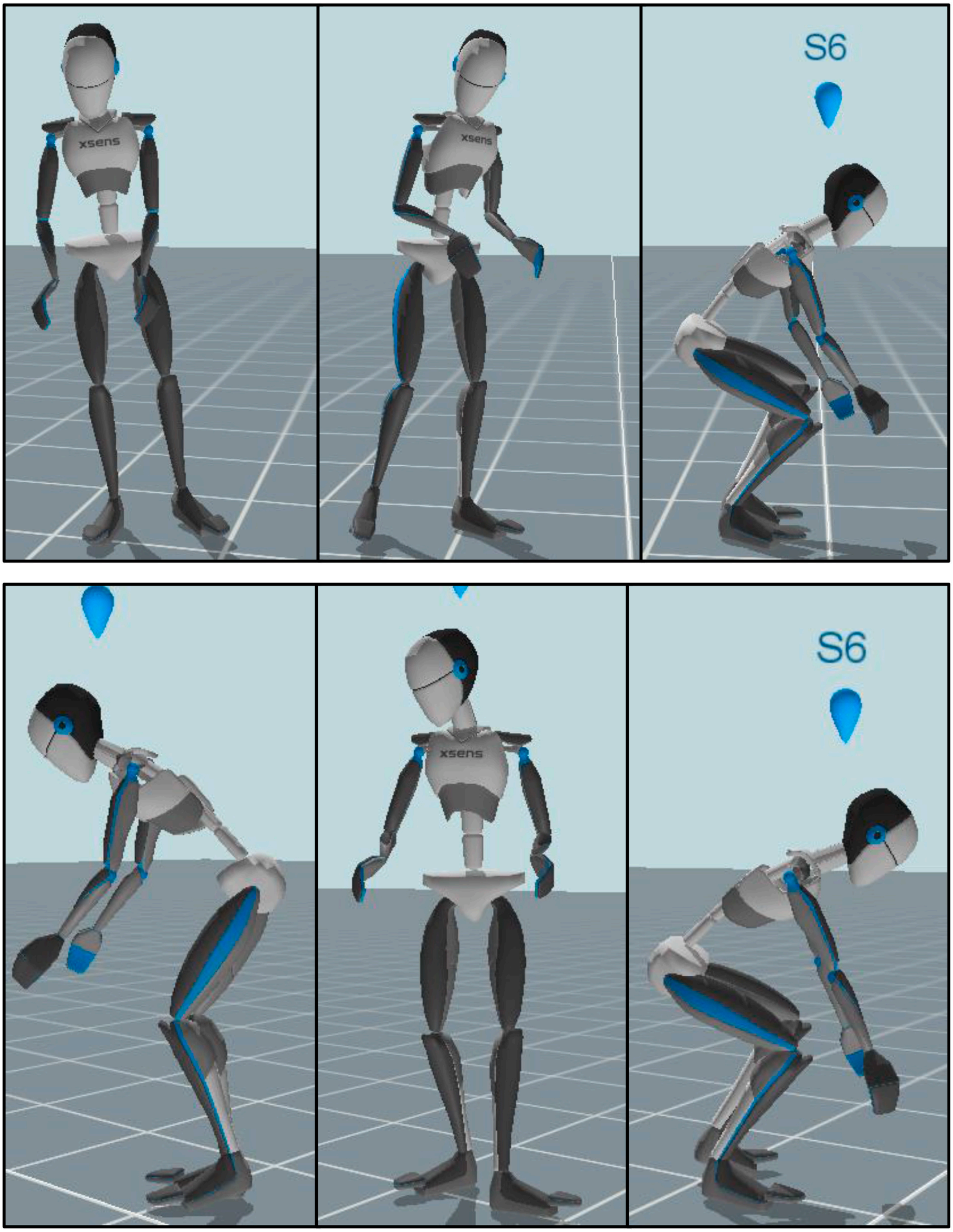


**Fig. 3.** Kinematic models during the start (right), mid (center) and end (left) of the lifting cycles for the tasks MD3-SP1-H3/Milk-LowToHigh (top) and FV1–SP1–H1/Bananas-LowToLow (bottom).

as 100 figures illustrating the joint angles over the complete lifting cycles are presented in a supplementary database (Skals et al., 2020). In the following, the selected results, presented in Tables 2–4, are summarized.

### 3.1. nEMG for trapezius descendens

The highest ranked tasks for the trapezius muscle activity were Bread-HighToHigh (59% and 56%) and Bread-LowToHigh (55% and 56%), followed by Cucumbers-HighToHigh (53% and 50%), ColdCuts-HighToHighFar (53% and 50%) and Cucumbers-LowToHigh (51% and 47%). The 10 highest ranked tasks (nEMG $\geq$ 31%) were all variations of handling bread, cucumbers, cold cuts and yoghurts lifted to the highest shelf heights (140.5–168 cm) with the heaviest lifts requiring the highest muscular effort (bread and cucumbers). However, the relatively light tasks, ColdCuts-HighToHighFar, showed some of the highest measured activity for trapezius (53% and 50%) despite weighing only 2.1 kg.

### 3.2. nEMG for erector spinae longissimus

For the erector spinae muscle activity, the highest ranked task was Cucumbers-LowToHigh (67% and 71%). Compared to the results for trapezius, the erector spinae muscle activities were higher overall and less varied with the 25 highest ranked tasks for the left and right side ranging from 43% to 71%. The results show a trend towards the heaviest lifts requiring the highest muscular effort, e.g. Bananas-LowToLow (59% and 63%), particularly when relatively heavy merchandise were moved from the lowest starting position to the highest shelf heights, e.g. Cucumbers-LowToHigh (67% and 71%), Bread-LowToHigh (60% and 63%) and Milk-LowToHigh (61% and 61%).

### 3.3. Knee and shoulder flexion peak angles

The MMH tasks requiring the highest amount of knee flexion were Yoghurts-LowToLow (108°) and Yoghurts-LowToHigh (105° and 107°). Overall, the tasks with the low starting position required more knee flexion, while the shelf height had less influence. Furthermore, the smaller boxes with merchandise (e.g. cold cuts and yoghurts) required a higher degree of knee flexion compared to the larger boxes (e.g. cucumbers and bread).

For shoulder flexion, the highest values were found for ColdCuts-HighToLowFar (109° and 110°), where the subjects had to place cold cuts at the far end of a low shelf. All but 3 of the 25 highest ranked tasks for both the left and right side involved flexing the shoulders more than 90°.

### 3.4. Trunk flexion/extension and rotation peak angles and ROM

The results for the peak trunk flexion and rotation angles showed that all of the 25 highest ranked tasks involved lifting with the trunk flexed almost 50° (from 48° to 59°, median 55°). Nineteen of the 25 tasks were initiated from the low starting position and all of the tasks involved either lifting from or placing the merchandise at a low height. For trunk flexion/extension ROM, the 5 highest ranked tasks all involved lifting from the lowest starting position to the highest shelf, e.g. Yoghurts-LowToHigh (52°) and ColdCuts-LowToHighNear (51°).

For the peak trunk rotation angles, there was no clear observable trend in relation to the characteristics of the MMH tasks, except the fact that multiple one-handed lifts were ranked in the top 25, e.g. VegetableOil-HighToLow (24°), MincedBeef-HighToLowFar (21°) and SingleYoghurt-HighToMid (21°). Similarly, multiple one-handed lifts also ranked highly with regard to trunk rotation ROM. For both variables, however, the results were very similar across the 25 MMH tasks with only a 7° and 9° difference between the highest and lowest values for the peak joint angle and ROM, respectively.

## 4. Discussion

In this study, we analyzed muscular efforts and working postures during MMH in the supermarket sector based on IMC and sEMG measurements performed at the workplace. The main goal of this approach was to provide an overview of the physical efforts required to perform MMH tasks inherent to the industry, and rank the tasks according to the selected variables in order to provide reference material for ergonomic interventions aimed at reducing the risk of WRMD. From the presented data, several MMH tasks as well as other workplace factors that may

**Table 2**
Muscle activities for the left (L) and right (R) trapezius descendens and erector spinae longissimus presented as percentage of maximal voluntary isometric contraction (%MVIC) with 95% confidence intervals. The 25 manual material handling tasks with the highest values are ranked from highest to lowest.

| Rank | Trapezius descendens (L) | | Trapezius descendens (R) | | Erector spinae longissimus (L) | | Erector spinae longissimus (R) | |
|---|---|---|---|---|---|---|---|---|
| | Task | %MVIC | Task | %MVIC | Task | %MVIC | Task | %MVIC |
| 1 | BR1-SP2-H3 | 59 (54–64) | BR1-SP1-H3 | 56 (51–62) | FV3–SP1–H3 | 67 (58–75) | FV3–SP1–H3 | 71 (62–80) |
| 2 | BR1-SP1-H3 | 55 (50–61) | BR1-SP2-H3 | 56 (51–62) | MD3-SP1-H3 | 61 (52–69) | FV3–SP2–H3 | 64 (55–72) |
| 3 | FV3–SP2–H3 | 53 (47–58) | FV3–SP1–H3 | 51 (46–56) | BR1-SP1-H3 | 60 (51–68) | BR1-SP1-H3 | 63 (54–71) |
| 4 | MD2-SP2-H3-D2 | 53 (47–58) | FV3–SP2–H3 | 50 (44–55) | FV1–SP1–H1 | 59 (51–68) | FV1–SP1–H1 | 63 (54–71) |
| 5 | FV3–SP1–H3 | 47 (42–53) | MD2-SP2-H3-D2 | 50 (44–55) | FV3–SP2–H3 | 57 (48–65) | FV3–SP1–H2 | 62 (53–70) |
| 6 | BR2-SP2-H3 | 44 (39–50) | BR2-SP2-H3 | 47 (41–52) | FV3–SP1–H2 | 56 (48–65) | MD3-SP1-H3 | 61 (53–70) |
| 7 | MD4-SP2-H2 | 42 (37–48) | MD4-SP2-H2 | 45 (39–50) | BR1-SP2-H3 | 56 (47–65) | FV2–SP1–H3 | 59 (51–68) |
| 8 | MD4-SP1-H2 | 40 (34–45) | MD4-SP1-H2 | 42 (37–47) | BR1-SP1-H2 | 55 (46–63) | MD4-SP1-H2 | 58 (50–67) |
| 9 | MD2-SP2-H3 | 32 (27–38) | MD2-SP2-H3 | 41 (36–47) | MD3-SP1-H2 | 53 (44–61) | MD3-SP1-H2 | 57 (48–65) |
| 10 | MD2-SP1-H3 | 31 (25–36) | MD2-SP1-H3 | 35 (30–41) | MD4-SP1-H2 | 51 (43–60) | BR1-SP2-H3 | 56 (48–64) |
| 11 | FV2–SP2–H3 | 29 (24–35) | FV3–SP1–H2 | 31 (26–37) | MD4-SP1-H1 | 51 (42–59) | BR1-SP1-H2 | 54 (46–63) |
| 12 | FV1–SP2–H1 | 29 (24–34) | MD2-SP2-H1 | 31 (26–36) | FV2–SP1–H3 | 50 (41–58) | MD3-SP1-H1 | 54 (45–62) |
| 13 | FV3–SP1–H2 | 27 (22–33) | FV2–SP2–H3 | 30 (25–35) | FV1–SP2–H1 | 48 (40–57) | MD4-SP1-H1 | 54 (45–62) |
| 14 | FV3–SP2–H2 | 27 (22–33) | FV3–SP2–H2 | 30 (24–35) | MD4-SP2-H2 | 48 (39–56) | FV2–SP1–H2 | 53 (44–61) |
| 15 | FV2–SP1–H3 | 27 (21–32) | MD3-SP2-H3 | 29 (24–34) | MD2-SP1-H3-D1 | 47 (39–56) | MD2-SP1-H3 | 52 (44–61) |
| 16 | MD3-SP2-H3 | 26 (20–31) | MD3-SP1-H3 | 28 (23–34) | MD3-SP1-H1 | 47 (38–55) | MD2-SP1-H2-D1 | 49 (40–57) |
| 17 | MD3-SP1-H3 | 25 (19–30) | FV1–SP2–H1 | 27 (22–32) | FV2–SP1–H2 | 47 (38–55) | MD4-SP2-H2 | 49 (40–57) |
| 18 | FV1–SP1–H1 | 25 (19–30) | FV2–SP1–H3 | 27 (21–32) | MD3-SP2-H1 | 47 (38–55) | CO1–SP1–H2 | 49 (40–57) |
| 19 | FV4–SP1–H4 | 24 (19–30) | FV4–SP2–H4 | 26 (21–31) | MD3-SP2-H2 | 46 (38–55) | FV4–SP1–H4 | 48 (40–57) |
| 20 | FV4–SP2–H4 | 24 (19–30) | MD3-SP2-H2 | 26 (20–31) | BR1-SP2-H1 | 45 (36–53) | FV1–SP2–H1 | 47 (39–56) |
| 21 | MD4-SP1-H1 | 24 (19–30) | BR1-SP2-H2 | 25 (20–31) | FV4–SP1–H4 | 44 (36–53) | FV3–SP2–H2 | 46 (38–55) |
| 22 | BR1-SP2-H2 | 23 (18–29) | FV4–SP1–H4 | 25 (20–30) | FV3–SP2–H2 | 44 (35–52) | BR1-SP1-H1 | 44 (36–53) |
| 23 | MD3-SP2-H2 | 22 (17–28) | CO2–SP2–H3 | 25 (20–30) | BR2-SP2-H3 | 44 (35–52) | MD3-SP2-H1 | 44 (36–53) |
| 24 | MD2-SP2-H1 | 22 (17–28) | MD4-SP1-H1 | 24 (19–29) | CO1–SP1–H2 | 43 (35–52) | MD2-SP2-H1-D2 | 44 (35–53) |
| 25 | BR1-SP1-H2 | 22 (17–27) | MD5-SP2-H2 | 23 (18–28) | MD3-SP2-H3 | 43 (35–52) | BR1-SP2-H2 | 44 (35–52) |

**Table 3**
Peak shoulder and knee flexion angles for the left (L) and right (R) side presented in degrees with 95% confidence intervals. The 25 manual material handling tasks with the highest values are ranked from highest to lowest.

| Rank | Shoulder flexion (L) | | Shoulder flexion (R) | | Knee flexion (L) | | Knee flexion (R) | |
|---|---|---|---|---|---|---|---|---|
| | Task | Peak | Task | Peak | Task | Peak | Task | Peak |
| 1 | MD2-SP2-H1-D2 | 109 (104–113) | MD2-SP2-H1-D2 | 110 (105–116) | MD4-SP1-H2 | 108 (100–116) | MD4-SP1-H2 | 108 (99–117) |
| 2 | BR1-SP1-H1 | 105 (101–110) | MD5-SP2-H2 | 109 (104–115) | MD4-SP1-H1 | 105 (97–113) | MD4-SP1-H1 | 107 (98–116) |
| 3 | FV4–SP2–H4 | 102 (98–107) | FV4–SP2–H4 | 109 (103–114) | MD2-SP2-H1-D2 | 98 (90–106) | MD2-SP2-H1-D2 | 100 (91–109) |
| 4 | BR1-SP1-H3 | 102 (98–107) | BR1-SP1-H3 | 107 (102–113) | MD2-SP1-H3-D1 | 94 (86–102) | MD2-SP1-H3-D1 | 98 (89–107) |
| 5 | BR1-SP2-H3 | 102 (98–107) | FV4–SP1–H4 | 107 (101–113) | FV3–SP1–H2 | 94 (85–102) | CO1–SP1–H2 | 94 (85–103) |
| 6 | FV4–SP1–H4 | 101 (97–105) | BR1-SP1-H1 | 106 (100–112) | FV3–SP1–H3 | 91 (83–99) | MD2-SP1-H2-D1 | 93 (84–103) |
| 7 | BR1-SP2-H1 | 100 (95–104) | CO2–SP2–H3 | 105 (99–111) | CO1–SP1–H2 | 90 (82–98) | FV3–SP1–H3 | 93 (84–102) |
| 8 | MD2-SP1-H1-D1 | 97 (93–101) | BR1-SP2-H3 | 104 (99–110) | MD2-SP1-H2-D1 | 90 (82–98) | FV3–SP1–H2 | 93 (83–102) |
| 9 | MD2-SP2-H3-D2 | 96 (92–100) | MD2-SP2-H3-2 | 104 (98–109) | FV2–SP1–H3 | 90 (82–98) | CO1–SP1–H1 | 90 (81–99) |
| 10 | MD2-SP1-H3-D1 | 96 (92–100) | FV2–SP1–H3 | 103 (97–108) | FV4–SP1–H4 | 89 (81–97) | MD2-SP1-H1-D1 | 89 (80–98) |
| 11 | BR2-SP2-H3 | 96 (91–100) | MD2-SP1-H3-D1 | 102 (96–107) | FV2–SP1–H2 | 88 (80–96) | FV4–SP1–H4 | 86 (77–95) |
| 12 | MD2-SP2-H3-D1 | 95 (91–99) | MD2-SP2-H3-D1 | 100 (95–106) | CO1–SP1–H1 | 86 (78–94) | FV2–SP1–H3 | 86 (77–95) |
| 13 | CO1–SP1–H1 | 94 (90–99) | FV3–SP1–H3 | 100 (94–106) | MD2-SP1-H1-D1 | 85 (77–93) | CO1–SP2–H1 | 85 (76–94) |
| 14 | MD2-SP2-H2-D2 | 94 (89–98) | BR1-SP1-H2 | 100 (94–105) | BR1-SP1-H3 | 83 (75–91) | BR1-SP1-H3 | 85 (76–94) |
| 15 | MD4-SP2-H2 | 93 (88–97) | MD2-SP1-H1-D1 | 99 (93–105) | CO1–SP2–H1 | 82 (74–90) | FV2–SP1–H2 | 85 (76–94) |
| 16 | FV2–SP2–H3 | 93 (88–97) | FV2–SP1–H2 | 99 (93–104) | BR1-SP1-H2 | 80 (72–88) | BR1-SP2-H1 | 79 (70–88) |
| 17 | MD2-SP2-H1-D1 | 93 (88–97) | MD2-SP2-H2-D2 | 97 (91–103) | BR1-SP1-H1 | 79 (71–87) | BR1-SP1-H2 | 78 (69–87) |
| 18 | FV2–SP1–H3 | 92 (88–97) | MD4-SP2-H2 | 96 (91–102) | BR1-SP2-H1 | 77 (70–85) | BR1-SP1-H1 | 77 (68–86) |
| 19 | MD4-SP1-H2 | 91 (87–96) | MD3-SP1-H1 | 96 (91–102) | FV1–SP1–H1 | 70 (62–78) | MD2-SP2-H1-D1 | 72 (63–81) |
| 20 | FV3–SP1–H3 | 91 (87–95) | BR2-SP2-H3 | 96 (90–102) | MD3-SP1-H3 | 67 (59–75) | FV1–SP1–H1 | 70 (61–79) |
| 21 | FV3–SP2–H3 | 91 (86–95) | FV3–SP2–H3 | 96 (90–102) | MD2-SP2-H1-D1 | 65 (57–73) | CO2–SP2–H1 | 66 (57–75) |
| 22 | FV2–SP1–H2 | 90 (86–94) | FV3–SP1–H2 | 96 (90–102) | MD3-SP1-H2 | 64 (56–72) | MD3-SP1-H3 | 65 (56–74) |
| 23 | CO1–SP2–H1 | 88 (84–93) | MD4-SP1-H2 | 95 (90–101) | MD3-SP1-H1 | 62 (54–70) | MD3-SP1-H1 | 64 (55–73) |
| 24 | FV3–SP1–H2 | 87 (82–91) | CO2–SP2–H1 | 94 (89–100) | CO2–SP2–H1 | 53 (45–61) | MD3-SP1-H2 | 62 (53–71) |
| 25 | FV2–SP2–H2 | 83 (79–87) | FV2–SP2–H3 | 94 (88–100) | MD4-SP2-H2 | 50 (42–58) | MD3-SP2-H1 | 50 (41–59) |

**Table 4**
Peak trunk flexion and rotation angles as well as flexion/extension and rotation ROM presented in degrees with 95% confidence intervals. The 25 manual material handling tasks with the highest values are ranked from highest to lowest.

| Rank | Trunk flexion/extension | | | | Trunk rotation | | | |
|---|---|---|---|---|---|---|---|---|
| | Task | Peak | Task | ROM | Task | Peak | Task | ROM |
| 1 | CO1–SP1–H1 | 59 (54–63) | MD4-SP1-H2 | 52 (49–56) | CO2–SP2–H1 | 24 (20–27) | BR2-SP2-H2 | 30 (26–34) |
| 2 | BR1-SP1-H1 | 58 (53–62) | MD2-SP1-H3-D1 | 51 (47–54) | MD2-SP2-H1-D2 | 24 (20–27) | CO2–SP2–H3 | 27 (23–30) |
| 3 | MD2-SP1-H3-D1 | 56 (52–61) | BR1-SP1-H3 | 48 (45–51) | CO2–SP2–H3 | 22 (19–25) | MD5-SP2-H2 | 25 (22–29) |
| 4 | MD2-SP1-H1-D1 | 56 (52–61) | FV4–SP1–H4 | 45 (42–49) | MD2-SP2-H2-D2 | 22 (19–25) | MD1-SP2-H1-D2 | 24 (20–28) |
| 5 | MD2-SP2-H1-D2 | 56 (52–61) | FV3–SP1–H3 | 45 (41–48) | BR2-SP2-H2 | 22 (19–25) | MD1-SP2-H1-D1 | 24 (20–28) |
| 6 | CO1–SP1–H2 | 56 (52–61) | MD4-SP1-H1 | 44 (41–47) | BR1-SP2-H1 | 21 (18–25) | MD2-SP2-H3-D2 | 24 (20–28) |
| 7 | CO1–SP2–H1 | 56 (51–60) | FV2–SP1–H3 | 38 (35–42) | MD1-SP2-H1-D2 | 21 (18–25) | MD2-SP2-H2-D2 | 24 (20–27) |
| 8 | MD2-SP1-H2-D1 | 56 (51–60) | MD2-SP1-H2-D1 | 38 (35–41) | CO2–SP2–H2 | 21 (18–24) | MD5-SP2-H1 | 24 (20–27) |
| 9 | FV3–SP1–H3 | 56 (51–60) | BR1-SP2-H1 | 34 (31–38) | FV4–SP2–H4 | 21 (18–24) | BR1-SP2-H2 | 24 (20–27) |
| 10 | FV3–SP1–H2 | 55 (51–60) | MD4-SP2-H2 | 33 (30–37) | MD1-SP2-H1-D1 | 21 (18–24) | FV4–SP2–H4 | 23 (20–27) |
| 11 | BR1-SP2-H1 | 55 (51–60) | FV3–SP1–H2 | 33 (30–37) | MD5-SP2-H2 | 21 (18–24) | BR1-SP2-H3 | 23 (19–27) |
| 12 | MD4-SP1-H1 | 55 (50–59) | CO1–SP1–H2 | 33 (30–36) | BR1-SP2-H2 | 21 (17–24) | MD2-SP1-H3-D1 | 23 (19–27) |
| 13 | MD4-SP1-H2 | 55 (50–59) | BR1-SP1-H2 | 33 (29–36) | CO1–SP2–H1 | 20 (17–23) | MD2-SP2-H2-D1 | 22 (19–26) |
| 14 | BR1-SP1-H2 | 54 (50–59) | MD3-SP2-H1 | 32 (29–35) | MD2-SP2-H1-D1 | 20 (17–23) | FV3–SP2–H3 | 22 (18–26) |
| 15 | BR1-SP1-H3 | 54 (50–58) | FV2–SP1–H2 | 32 (28–35) | MD2-SP2-H3-D2 | 20 (17–23) | FV1–SP2–H1 | 22 (18–26) |
| 16 | FV2–SP1–H2 | 54 (49–58) | MD2-SP2-H1-D2 | 31 (27–34) | FV2–SP2–H2 | 19 (16–23) | MD2-SP2-H1-D2 | 22 (18–26) |
| 17 | MD3-SP1-H1 | 54 (49–58) | CO1–SP2–H1 | 30 (26–33) | MD5-SP2-H1 | 19 (16–23) | FV4–SP1–H4 | 22 (18–26) |
| 18 | MD2-SP2-H1-D1 | 53 (49–58) | MD2-SP2-H3-D2 | 29 (25–32) | FV2–SP2–H3 | 19 (16–22) | FV2–SP2–H2 | 21 (18–25) |
| 19 | FV4–SP1–H4 | 53 (49–58) | MD2-SP2-H1-D1 | 28 (25–32) | FV1–SP2–H1 | 19 (16–22) | CO1–SP2–H2 | 21 (17–25) |
| 20 | FV2–SP1–H3 | 52 (48–57) | MD2-SP2-H3-D1 | 27 (24–30) | BR1-SP2-H3 | 19 (16–22) | MD3-SP2-H3 | 21 (17–25) |
| 21 | FV1–SP1–H1 | 51 (46–55) | FV1–SP1–H1 | 26 (23–30) | MD2-SP2-H2-D1 | 19 (16–22) | FV2–SP2–H3 | 21 (17–25) |
| 22 | CO2–SP2–H1 | 50 (45–54) | CO2–SP2–H1 | 24 (21–27) | CO1–SP2–H2 | 18 (15–21) | MD2-SP1-H2-D1 | 21 (17–25) |
| 23 | MD3-SP1-H2 | 49 (45–53) | MD3-SP1-H3 | 24 (21–27) | FV4–SP1–H4 | 18 (15–21) | MD2-SP2-H3-D1 | 21 (17–25) |
| 24 | MD3-SP2-H1 | 48 (44–53) | FV4–SP2–H4 | 22 (19–26) | BR2-SP2-H3 | 17 (14–20) | FV2–SP1–H3 | 21 (17–25) |
| 25 | MD3-SP1-H3 | 48 (43–52) | CO2–SP2–H3 | 22 (18–25) | MD3-SP2-H3 | 17 (14–20) | CO2–SP2–H2 | 21 (17–25) |

pose a risk for developing WRMD were identified, which are discussed in the following.

The MMH tasks that exposed the workers to the highest muscular demands where variations of bread, milk, bananas and cucumbers. This is not surprising since bananas and milk are by far the heaviest merchandise (20.2 and 17.3 kg, respectively), while bread and cucumbers were considerably lighter (7.9 and 10.2 kg, respectively), but involved moving the merchandise from a low to a high position. From the conversations with the industry stakeholders, it was clear that they were well-aware that handling milk crates and bananas were strenuous for the workers, which the presented data confirms: for example, Milk-LowToHigh and Bananas-LowToLow showed muscle activities for erector spinae around 60%. What might be more surprising was that equally high or higher loads on the low back muscles were observed when bread and cucumbers were lifted to the highest shelfs (from 56% to 71%, median 61.5%), while simultaneously requiring the highest muscular effort for trapezius (from 47% to 59%, median 54%). Finally, another interesting finding was that even a MMH task of relatively light weight, ColdCuts-HighToHighFar, showed some of the highest trapezius activity (50% and 53%), probably due to the combination of a high shelf height and long reaching distance. Thus, supermarkets – as well as other workplaces where manual handling is performed – should be aware that even light external loads can require high muscular efforts due to unfavorable ergonomic work factors.

One general risk factor for WRMD that can be identified from the presented data was the large proportion of tasks that required high degrees of shoulder flexion. There were mainly two contrasting scenarios that resulted in shoulder flexion angles above 90°: lifting to a high shelf (≥140.5 cm) as well as placing merchandise on a low shelf, which showed a combination of high trunk and shoulder flexion. As working above shoulder height (Van Rijn et al., 2010; Mayer et al., 2012; Svendsen et al., 2004; NIOSH, 1998) as well as working in awkward postures (da Costa and Vieira, 2010; Fernandes et al., 2016; Fransen et al., 2011; Reid et al., 2010; NIOSH, 1998) has been identified as risk factors for WRMD, it is alarming that many of the common MMH tasks in the supermarket sector exposes the workers to these risks. If we compare the two scenarios in regards to trapezius muscle activity, it is clear that lifting merchandise to above shoulder height required much higher muscular effort than placing merchandise on low shelfs; the 10 highest ranked tasks for this variable involved lifting to the highest shelf heights. However, the combination of high shoulder and trunk flexion when lifting and placing items should be a cause for concern, as this load-posture combination requires a high muscular effort in the lower back. One example from the dataset was Bread-LowToLow, which showed peak trunk and shoulder flexion angles of 58° and 106°, and muscle activities of 43% and 44% for the left and right erector spinae, respectively.

When viewing the peak trunk flexion angles, it is also notable that all of the 25 highest ranked tasks involved forward flexing the trunk more than 48° relative to the pelvis. As was noted previously, the majority of the tasks requiring large trunk flexion were initiated from the low starting position (15 cm above the floor). If we compare the peak trunk flexion angles between two identical lifts with different starting positions, as for instance, Bread-LowToMid and Bread-HighToMid, we see a difference of 27°. Furthermore, when comparing the same tasks, the results show differences of 11% and 10% for the left and right erector spinae, respectively, indicating the potential benefits of lifting from waist height rather than from near the ground, as it can significantly reduce the load on the lower back (Waters et al., 1993; Lavender et al., 2003; Hoozemans et al., 2008). Thus, transport devices that allow the employees to adjust the lifting height, for instance, could possibly reduce the risk of low back pain during stocking activities in supermarkets.

Besides putting a higher load on the muscles, the low starting position and shelf heights require a higher degree of knee flexion. This is evident from the presented data, where almost all the 25 highest ranked tasks for left and right knee flexion where initiated from the low starting position with the top 10 tasks requiring knee flexion over 89°. In addition, it is common for the supermarket workers to perform light stocking activities on the lower shelves in a kneeling position. Kneeling or squatting for prolonged periods during work has been associated with an increased risk of developing knee disorders (Reid et al., 2010), while the combination of heavy lifting and squatting increases this risk significantly (Fransen et al., 2011). Despite squat lifting being commonly advocated to reduce the load on the lower back, the scientific evidence supporting this recommendation is questionable (van Dieën et al., 1999; Straker, 2003). For these reasons, it seems most reasonable to recommend that the low shelves should be avoided whenever possible instead of dwelling on the techniques used to handle items in these heights. When low shelf heights cannot be avoided, proper technical assistive devices could be implemented to reduce the load.

As mentioned previously, only two previous studies have conducted direct measurements of MMH in a supermarket context (Balogh et al., 2016; Silvetti et al., 2015). Silvetti et al. (Silvetti et al., 2015) found erector spinae peak muscle activities between 26.3% and 75.1%, and trunk flexion/extension ROM from 3.6 to 22.9° when lifting a 6 and 8 kg crate to four levels (36–136 cm above floor level) of a supermarket shelf in a laboratory setting. In comparison, our results showed erector spinae peak muscle activities and trunk flexion/extension ROM ranging from 43% to 71% and 22°–52° for the 25 highest ranked tasks, respectively. Hence, while the muscle activities in the lower back were very similar between the two studies, the measured postures differed substantially, indicating the importance of performing workplace measurements that more accurately reflect actual working conditions. Balogh et al. (Balogh et al., 2016) performed their measurements at the workplace, but only provided an overall estimate of muscular efforts for different job categories. They reported right trapezius muscle activity (90th percentile nEMG) for picking, cashier, delicatessen and mixed work of 20.1%, 10.9%, 18.3% and 15.7%, respectively. Our data showed average 90th percentile nEMG for the right trapezius across all 50 analyzed tasks of 21.4% (see supplementary database (Skals et al., 2020)), which supports the finding of Balogh et al. (Balogh et al., 2016) that stocking or picking work appear to be the most strenuous job category for the upper trapezius within supermarkets. When comparing the results to other jobs involving MMH, a study by Plamondon et al. (2006) provides some interesting context. They studied drill operators lifting a vertical 35 kg drilling rod from different lifting heights and asymmetry angles, as well as a 21.5 kg symmetrical box lift designed to produce a NIOSH lifting index (Waters et al., 1993) equal to the action limit (1.0) for safe lifting. They found erector spinae peak nEMG from 48% to 83%, median 68.5%, and peak trunk flexion angles between 42° and 51°, median 47°, while the reference lift resulted in peak muscle activity of 63.5% and a lifting index of 1.4. In view of these results, several of the analyzed tasks in the present study likely exceeded the NIOSH action limit, while most of the 25 highest ranked tasks showed comparable muscular demands to a substantially heavier manual handling task performed in industrial mining.

A number of limitations should be noted. First, signal dropout and poor skin-electrode contact are well-known issues related to sEMG (Farina et al., 2004, 2014), which were also present in this study and meant that many trials had to be excluded. However, visual inspection of all raw and filtered sEMG signals as well as controlling for extreme measurements post-processing ensured that only data of sufficient quality were included in the analysis. In addition, we chose to exclude 12 measurements where the peak nEMG exceeded 150% of MVIC. These extreme measurements were probably caused by an unnoticed spike in sEMG amplitude during a few tasks combined with submaximal MVICs for some subjects; obtaining a true maximum effort from untrained individuals at their workplace is very challenging. Second, while the IMC system is the newest available technology to measure full-body kinematics outside a laboratory environment, the accuracy of the system is not equivalent to marker-based motion analysis (Larsen et al., 2020; Koning et al., 2015; Karatsidis et al., 2019). More specifically, the IMC system may underestimate the trunk forward flexion angles by up to 17° during standardized lifting activities (Larsen et al., 2020), while the lower limb kinematics has generally shown higher accuracy, particularly in the sagittal plane (Karatsidis et al., 2019). However, compared to other field methods, such as video recordings or single IMUs, the system provides a much greater level of detail and more well-founded criteria for estimating joint angles. Third, as no exact criteria exists for determining the risk of musculoskeletal pain or injury in relation to nEMG, no inferences can be made regarding causal associations between the loads presented in this study and WRMD. For this reason, we focused mainly on the relative muscular loads when interpreting the data, which is still highly useful for identifying the most hazardous MMH tasks in the industry. However, a recent study by Giannini et al. (2020) presented a methodology for overall risk assessment based on sEMG and inertial-based kinematics, incorporating well-known risk assessment tools, such as The Revised NIOSH Lifting Equation (Waters et al., 1993), Snook Tables (Snook and Ciriello, 1991) and Rapid Entire Body

Assessment (REBA) (Hignett and McAtamney, 2000). Future studies could advantageously implement this type of methodology to provide a more complete risk assessment that applies these direct measurements in unison. Fourth, to facilitate the use of musculoskeletal model analysis (described in part 2) based on the kinematic data obtained in the present study, we instructed the workers where to place and keep their hands during the tasks. For the merchandise that had handles on either side (e.g. bananas, milk and cucumbers), this restriction did not substantially alter the normal handling practices, but for other smaller boxes (e.g. yoghurts and cold cuts) and during the one-handed lifts, this may have inhibited the subjects from handling the merchandise as they normally would. Furthermore, as we decided where to place the transport cage in relation to the shelves as well as asking the subjects to perform four consecutive repetitions, we further influenced the work conditions. Hence, it should be emphasized that although we believe that our procedures encapsulate many important work factors, such as the starting positions, shelf heights and store layout, the study does not accurately replicate real-life working conditions. This would involve much more variability as well as other types of handling, e.g. re-packaging merchandise from pallets to other transport devices. Furthermore, aspects of fatigue related to repeated tasks were also not included. Consequently, a limitation is that we could not – adhering to standardized procedures – replicate all physical work factors in one study. Fifth, magnetic distortions from the surrounding environment (e.g. refrigerators, shelves etc.) may have caused orientation and positional drift in the kinematic data. This is a well-known issue when using IMUs, but to what extent these distortions influenced the data is unknown. To minimize the influence of these distortions, we performed frequent calibrations of the system (e.g. before initiating each series of lifts in a food category and whenever we noticed a slight drift of the kinematic model) and continuously visually inspected the kinematic data. However, it should be noted that significant efforts have been made by the developers of the IMC system to correct for drift during measurements using an advanced Kalman filter (Paulich et al., 2018) as well as a post-processing tool (HD re-process) in the accompanying software that improves the consistency and precision of the kinematics and global position estimation. In contrast to the Kalman filter that only calculates forward in time, the re-processing tool makes use of the whole trial duration to estimate a non-homogenous magnetic field.

## 5. Conclusions

This paper provides a comprehensive overview of the muscular efforts and working postures required to perform common MMH tasks in the supermarket sector based on IMC and sEMG measurements from two supermarkets. We found that the handling of bananas, milk, cucumbers and bread required the highest muscular efforts for trapezius descendens and erector spinae longissimus, particularly when lifted from a low to a high position. Furthermore, a large proportion of the analyzed tasks involved undesirable working postures, as 22 tasks involved flexing the trunk more than 50°, while 22 tasks involved flexing both shoulders more than 90°. Finally, several tasks involved a combination of high trunk and shoulder flexion or excessive squatting. Based on these findings, we recommend that the handling of bananas, milk, cucumbers and bread should be reconsidered to reduce the muscular demands on the lower back and shoulders, while undesirable working postures should be minimized through ergonomic intervention, possibly involving the implementation of simple assistive devices, technical assistive devices, re-designing shelves and changing the placement of heavy merchandise.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Conflicts of interest

The authors have no conflicts of interest to declare.

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