

Materials and Methods

1. Participants

Nine male subjects [26.1 years (± 5.6 years), 180.2 cm (± 6.1 cm), and 99.7 kg (± 27.6 kg)] without any prior expertise in roofing participated in this study. No individual had any known neurological or MSD conditions. The research protocol was reviewed and approved by the Institutional Review Board (IRB) of the National Institute for Occupational Safety and Health (NIOSH). Before participating in the research, the participants read and signed an informed consent document.

2. Instruments

This study used an optical motion capture system featuring 14 MX cameras - VICON (Oxford, UK) to collect endpoint data of the participants. A total of 42 retroreflective markers were affixed to the lower extremities of the participants, including their feet, heels, toes, ankles, shanks, knee joints, thighs, and hip joints. The three-dimensional (3D) coordinates acquired from these markers were utilized for computing knee angles. The kinematic data were recorded at a rate of 100 Hz.

A custom-built wooden platform measuring 1.2 by 1.6 meters was employed to replicate the surface of a roof during shingle installation. This platform could be adjusted using a battery-powered lift, allowing for slope angles to be set anywhere between 0° and over 30° with the assistance of two sets of wooden support legs.

The pneumatic nail gun (Model RN46-1, Bostitch, North Kingstown, RI) used in this study weighed 2.5 kg. The KSs and KPs were generic off-the-shelf products. The shingles (3-tab Roof Shingle, Model MA20, Owens Corning, Toledo, OH) had a dimension of 0.91×0.30 (m) and a weight of 1.1 kg per piece. The selected pneumatic nail gun, KSs, KPs, and shingles were considered representative of construction sites.

3. Procedure

The experiments were performed in NIOSH's biomechanics laboratory. Participants were fitted with motion capture markers for kinematic calibration and data collection when they arrived at the laboratory. Before data collection began, participants were positioned to kneel on the roof simulator in an upright position. When told to start, participants first reached for two shingles and placed them in front of themselves. Then, they took up the nail gun from their right side and using the nail gun inserted six nails—three into each of the two shingles—one on each side, starting from the left and working their way to the right. The participants then placed the nail gun at its starting location and returned to their starting/resting positions. The participants completed the shingle installation assignment in seven phases as a single continuous action. Each participant completed the simulated shingle installation task on the roof simulator at three different slope angles (Figure 3)—0°, 15°, and 30° under four different intervention conditions—no wearable assist device (NO), knee pads only (KP), knee savers only (KS), and both knee pads and knee savers (BO), leading to 12 combinations. For each combination, five trials were recorded.

4. Definition of Phases in Shingle Installation

During a typical process of roof shingle installation, roofers use a pneumatic nail gun to fasten the shingles. This process begins with roofers first reaching for the shingles and then positioning them, facing forward, on the rooftop surface. Subsequently, they take the nail gun from its designated location, preparing to secure the shingles. Afterward, they proceed to nail the shingles side by side. The shingle installation process is concluded by returning the nail gun to its original position and the roofer returning to the initial kneeling position. In general, this process can be divided into seven phases: (1) reaching for shingles, (2) placing shingles, (3) grabbing a nail gun, (4) moving to the first nailing position, (5) nailing shingles, (6) replacing the nail gun, and (7) returning to an upright position.

5. Variables

This study used two factors to assess the effectiveness of interventions in reducing knee MSD risks during shingle installation. They were roof slopes (0°, 15°, and 30°) and wearable devices - no wearable assist devices (NO), knee pads only (KP), knee savers only (KS), and both knee pads and knee savers (BO). These roof slope angles were selected according to typical roof pitches observed on building sites. The KPs and KSs were chosen on account that many severe postures in the lower extremity during deep/full kneeling in the resting position of roof workers were reduced with the addition of these devices.

This study assumes that knee MSD risks are associated with knee rotations during shingle installations. The knee rotation was considered a dependent variable that reflects the effectiveness of interventions in reducing knee MSDs.

Over the seven phases of shingle installation, this study measured five types of knee rotation angles: flexion (around the side-to-side axis), abduction and adduction (around the front-to-back axis), and internal and external rotations (around the lengthwise axis). Deep bending movements exert significant force and torque on the knee joint. Elevated levels of knee movement toward and away from the body's midline subject the knee joint to stress, elevating the risk of developing knee osteoarthritis. When the tibia undergoes internal and external rotations relative to the femur, it places additional strain on the knee joint's ligaments.

6. Data Processing

The knee motions in three axial rotations (i.e., flex/extension, ad/abduction, and in/external rotation) along time were obtained in Visual 3D version 6 using the coordinates of the recorded markers. Using these data, the maximum values of knee rotation angles were computed, resulting in 315 (9 subjects × 5 trials × 7 phases) data points for each knee rotation angle in a specific knee under each combination of slope and intervention conditions.