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Biomechanical Assessment while Using Production Tables on Mast Climbing Work Platforms

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Abstract

The objective of this study was to assess the impact of using alternative mast climbing work platform (MCWP) designs on trunk motion and postural stability with masonry workers while performing bricklaying and stepping down tasks using a conventional MCWP setting (i.e. with the step deck) as well as two types of production tables (straight- and L-shaped). The trunk angles and postural sway parameters of twenty-five masonry workers were recorded for the following tasks: (1) standing on a simulated MCWP and laying bricks on an adjacent wall, and (2) stepping down onto the step deck to get into position for doing the bricklaying task. Results indicated that the use of the L-shaped production table resulted in the lowest trunk ranges of motion and significantly reduced the workers' trunk angles in all three planes when compared to both the straight-shaped production table and the conventional approach of not using a production table. Body sway data showed that both velocity and area were significantly reduced when using either one of the production tables. The use of production tables significantly reduced impact sway forces when workers stepped from the main platform to the step deck. The use of production tables on MCWPs improved workers' postures and overall stability, which could reduce the risk of injury.

Keywords

Mast Climbing Work Platform; Production Table; Back Injuries; Falls

Disclaimers
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1. Introduction

Mast climbing work platforms (MCWPs), or mast climbers, are an elevating equipment, that have been available in the United States since the 1980s. Due to their advantages, MCWPs have become more common throughout the 1990s and 2000s, and their popularity has continued to increase. An essential factor in all MCWPs is a powered drive unit that moves the work platform up and down a vertical mast structure. MCWPs are capable of handling much greater loads (including workers and materials) than traditional scaffolding. They also make reaching greater heights much easier, thereby improving efficiency of construction projects. MCWPs can be configured in many different ways, from freestanding models that can be used on shorter working heights to anchored models that can reach heights of over 1,000 feet. MCWPs are used as an alternative to traditional pole, tubular and coupler scaffolds. Their use frequently avoids idle time for specialty contractors (e.g., masons and labors) and setup crews thus increasing productivity.

Even though MCWPs have been available since the 1980s, there are limited studies in the occupational safety literature concerning their impact on worker safety and health. Published or peer-reviewed materials elucidating the occupational-hazard component of continued use of MCWPs are difficult to find, but such hazards are apparent based on the reported incidence of injuries and concerns of users, standards committees, renters and manufacturers (ANSI, 2011; O’Shea, 2014; Wimer et al., 2017). The hazards currently recognized with using this type of equipment are based on input from industrial manufacturers and observations by renters and users of MCWPs which have formed the basis for this project (O’Shea, 2014).

The rate of adopting MCWPs for use on construction sites is high and increasing, especially among masons and other specialty contractors (Susi et al., 2010). Construction job bidders and planners frequently specify mast climbers in contract proposals. This is due to several reasons: 1) there are productivity advantages to using MCWPs; 2) time-to-completion of construction projects is frequently a function of the availability of mechanized elevating equipment (Pan et al., 2012[a]); 3) these equipment technologies frequently shorten the period of construction; and 4) their use allows for rapid, purposeful scheduling of job activities. However, little ergonomic and safety research have been conducted on the safety of MCWPs.

Of the 22,000 MCWPs in use in the United States, roughly 70% are used daily (O’Shea, 2014). If an average of three to four construction workers are on the equipment at any given time completing a task, and numerous workers set up, move, assemble and dismantle MCWPs, and an equal or greater number of specialty contractors—painters, masons, siding installers—make use of this equipment to perform job tasks, then potentially as many as 50,000 U.S. workers can be using MCWPs on a given day. One great advantage of mast climbers is the ability to assemble/dismantle the equipment readily and easily, allowing it to be moved and used at different areas of a construction site. A personal communication from O’Shea (2014) has estimated that each mast climber could be disassembled and re-erected up to four or five times per year. Each move can take more than 30 hours with two trained erectors, thus creating up to 6.6 million-man hours in the moving process each year. It is often during the assembly/dismantling of equipment that incidents have occurred.

Over the past decade, MCWPs are increasingly used at construction worksites in the United States and have been involved in several incidents that have seriously injured workers and some have resulted in fall-related fatalities (Pan et al., 2012[a]; Susi et al., 2010; Wimer et al., 2017). A recent study in the construction industry showed that from 2011 to 2015 there were a total of 1,533 fatalities caused by fall to a lower level (CPWR, 2018). Among them, close to 15% were related to scaffolds/staging. In addition, in the year 2015 alone there were 12,100 nonfatal fall injuries related to scaffolding due to slips, trips, and falls (STFs) on the same level that have resulted in days away from work (CPWR, 2018). MCWPs are currently categorized as scaffolds (CPWR, 2018; Earnest and Branche, 2016; Pan, 2012[a]), but unfortunately are not considered separately in available surveillance data. Another study showed that between 2011 and 2016, the number of fatalities where scaffold/staging were the primary cause remained high and the total number of fatalities in these 6 years reached 408 (BLS, 2018). Up to 2010, at least 12 documented MCWP incidents have resulted in 18 deaths (Susi et al., 2010). Fall-related injuries have been responsible for fatalities in each of these cases. From 1990 to 2017, there were a total of 35 recorded fatalities associated with the use of mast climbers. Most of these fatalities were linked to issues with the platform structures during the process of dismantling the equipment. Of the 35 fatalities, 13 were masonry workers followed by plasterers (9 fatalities), and other various construction trades (13 fatalities) (OSHA, 2018; Pan et al., 2018).

In relation to musculoskeletal and gait-related injuries, walking and working on the surface of a MCWP could expose workers to balance and stability challenges due to the unstable nature of the MCWP at heights compared with a rigid ground surface (Wimer et al., 2017). Previous studies have shown that when performing manual material handling tasks while standing on uneven ground surfaces, especially wobbling work surfaces, participants demonstrated reduced standing stability (Lin & Nussbaum, 2012), altered trunk biomechanical responses and elevated risks of injury (Ning & Mirka, 2010; Hu et al., 2013, 2016; Zhou et al., 2013, 2015).

Working on a MCWP also creates awkward working postures due to the confined workspace and work surface. Prolonged and/or repeated use of these awkward postures could introduce muscle strain and fatigue, which may lead to further injuries (Marras et al., 1993; Hu & Ning, 2015[a], 2015[b]; Hu et al., 2016) and reduced productivity (Lotters et al., 2005). To reduce STFs and enhance fall prevention, incorporating MCWP work surface design improvements (e.g., a level working deck) becomes critical to avoid tripping hazards (Pan et al., 2012[a]).

Masonry workers also experience frequent back injuries associated with various manual material handling tasks when working at heights. For masonry workers, the prevalence for back disorders is 45-50% higher than that of other body parts (CPWR, 2018). Presently, it is common practice for masons to store their bricks and other materials directly on the MCWP’s main platform while they work from the lower planked level next to the relevant workspace (OSHA, 2018). Nevertheless, OSHA data have shown that in 2015 there was a fatal 100-foot fall incident while a masonry worker was stepping from the main working platform to the planked working deck two feet below (OSHA, 2018; Pan et al., 2018).

Based on the above observations, the objective of this study was to assess the impact of using alternative workplace MCWP designs on trunk posture and standing stability with masonry workers using a traditional MCWP setting (i.e. with the step deck) as well as two different production tables. The hypothesis of this study is that use of production tables on the MCWPs would reduce the potential for back injury and whole-body postural instabilities.

2. Methods

2.1. Participants

A total of 25 male construction workers (Age: 33.4±10.1 years; Height: 181.8±6.1 cm; Weight: 87±19.2 kg), with at least 6 months of masonry work (and bricklaying tasks) experience participated in this study. All participants completed a health-history screening before participating in the study to ensure they had no history of dizziness, tremors, vestibular disorders, neurological disorders, diabetes, chronic back pain, and falls within the past year resulting in injury with days away from work. Each participant gave informed consent according to the procedures approved by the National Institute for Occupational Safety and Health (NIOSH) Institutional Review Board (IRB).

2.2. Experimental Design and Data Processing

The experimental design involved two independent variables: 1) CONDITION (three levels of a simulated workstation): (i) conventional (i.e. using no table), (ii) use of a straight-shaped production table designed by a MCWP manufacturer and (iii) use of an L-shaped production table designed by NIOSH; and 2) FLEXIBILITY (maximal vs. minimal platform surface flexibility). Flexibility or structure stability was defined as the ratio of the vertical displacement of the main platform surface in relation to a vertical load positioned at a point on the platform (Dong et al., 2012). There were three groups of dependent variables: (i) trunk range of motion; (ii) whole-body sway data and; (iii) ground impact forces. For this study, trunk of the body is defined to include both back (spine) and pelvic region (pelvis) (BLS, 2020).

2.3. Simulated Workstation

An instrumented workstation of a typical MCWP arrangement for bricklaying masons was constructed in the NIOSH laboratory (Figure 1). The workstation represents a mechanical-equivalent system of a typical MCWP and reproduces the dynamic characteristics of those experienced by workers on a representative MCWP. The specially designed and adjustable suspension systems and support structures make the dynamic responses of the simulator's platform equivalent to that of an elevated MCWP, although the workstation in the current study was placed on the ground for safety reasons. A simulated "wall" was constructed in the front of the participants and used for laying bricks to simulate masonry work.

Two production tables (straight- and L-shaped) were evaluated in this study (Figure 2). The difference between these two production tables is that the NOISH "L" table added a perpendicular section to the manufacturer's straight-shaped table allowing the building materials (e.g., bricks) to be placed on the right side of masonry workers facing the bricklaying wall (Figures 1 and 2).

Four spring-damper systems were used to support the simulated MCWP workstation to mimic the flexible platform surface and unstable work conditions that exist on an actual elevated MCWP (Figures 1 and 3). These adjustable dampers allowed for the movement of the platform (flexibility or structure stability) to be adjusted according to measured values found on typical mast climber configurations. The flexibility or structure stability conditions used in this study were determined using the following method:

1. A person walking/moving on the platform served as the load/weight. The loading point on the platform was measured at a distance from the center of the mast structure and was taken at the middle of the platform section at the platform surface height

2. The platform displacement of a freestanding, elevated MCWP platform was measured at one of the NIOSH testing field sites (Pittsburgh, PA). As an initial measurement experiment and for safety reasons, the MCWP elevation was held to a height of 1-foot (0.3-meter) from the bottom of the ground base bump stops (lowest position). The measured vertical displacements were measured at select horizontal distances from the center of the mast structure and were recorded, respectively: (a) a vertical displacement of 0 inches (0 centimeters) at a horizontal distance of 5 feet (1.5 meters); (b) a vertical displacement of 0.5 inches (1.3 centimeters) at a horizontal distance of 15 feet (4.5 meters); and (c) a vertical displacement of 0.75-1 inches (1.9-2.5 centimeters) at a horizontal distance of 30 feet (9.1 meters). We selected four off-the-shelf extreme mount spring-damper systems (each with a maximum capacity of approximately 650 pounds or 295 kilograms) that had a stiffness of 520 pounds (236 kilograms) per 0.75 inch of displacement.

The test conditions mimicked the platform displacement that workers might experience while working on a MCWP. The dampers were built into the four bottom corners of the simulated workstation platform section to support its entire weight (Figures 1 and 3). At the lowest setting, the platform had minimal movement while a worker performed the bricklaying task (0 inches of displacement). With the spring-damper systems set at the highest setting, the platform had the most movement (a vertical displacement of approximately 0.75-1 inch of movement) during the bricklaying task.

Subjects were also asked to perform a "stepping-down" task. The stepping-down task simulates a worker stepping down from a MCWP onto the step deck to get into position for doing the bricklaying task (Figure 4). Test subjects were asked to step onto foot-shaped icons (see Figure 2) placed on the force plate by NIOSH researchers (Figure 4). This task was done without the presence of a production table. The walking-forward task was done with both production table configurations to simulate the worker walking forward to begin the work task. Again, test subjects completed the task by placing their feet on the icons on the force plate (Figure 2). A 5-minute rest period was given between trials to reduce the effects of fatigue on standing stability and postural sway.

2.4. Biomechanical Apparatus

Biomechanical data were collected via a motion capture system (Vicon Nexus, Denver, Colorado) synched with two force platforms (Bertec 4060-08, Columbus, Ohio). The motion system used six motion capture system cameras (MX-T10) mounted on the walls of the laboratory to determine joint kinematics (motions). Images from the cameras were combined to capture the three-dimensional position of the reflective markers worn by the test subjects. Two Bertec force plates were used to determine impact forces and postural sway in each of the experimental conditions (Figure 5). Two additional high-speed Vantage motion capture cameras mounted on tripods were synchronized with the other six MX-T10 motion capture system cameras to allow for post-test review of the tasks. The study team followed the standard calibration procedures for the Bertec instruments. A comparison of the force data collected on the simulated workstation and at ground level found no significant differences. The sampling frequencies for the Vicon cameras and Bertec force plate were 100 Hz and 1000 Hz, respectively. Data were filtered using Woltring (digital) and Butterworth (analog) filters. Full body modeling was done with the Vicon Motion Systems Plug-in Gait model for the upper body to calculate kinematics information.

2.5. Dependent Measures

The complexity of postural sway and stability of a human body cannot simply be represented by just one variable. Eight variables evaluated postural sway and propensity of instability based on the participant's center of pressure (COP) data measured on a force plate during the experiment. The eight variables related to posture sway were: mean speed (Speed, V); anterior-posterior speed (V AP); medial-lateral speed (V ML); confidence circle area (CC Area); confidence ellipse area (CE Area) (Zolghadr et al., 2018); frontal plane force (Fx); sagittal plane force (Fy); and transverse plane force (Fz) (Zolghadr et al., 2018). Three variables were selected to evaluate back injury potential based on each participant's trunk range of motion (ROM) on frontal, transverse, and sagittal planes including both spine and pelvis.

2.6. Experimental Procedures

Subjects came to the laboratory for one day of testing. Upon arrival, subjects were required to review experimental procedures and provide informed consent, which were both approved by the NIOSH IRB. Subjects first completed a health-history screening, followed by collection of basic anthropometric data including body mass, height, leg length, anterior superior iliac spine (ASIS) trochanter distance, knee width, ankle width, elbow width, hand thickness, and shoulder offset. Next, subjects completed a five-minute warm-up session that included arm stretching, squatting and back bending/stretching to reduce the risk of injury during the experiments. Subjects were then instructed and familiarized with the experimental apparatus and bricklaying task by a NIOSH researcher. Each test subject was outfitted with motion capture markers set using Full Body Plug-in Gait Modeling with clusters, and their joint kinematics were determined by using the Vicon Nexus motion capture system to compare postures (Figures 1 and 5).

Subjects wore tightly fitted clothing and safety shoes, provided by NIOSH, while performing a simulated bricklaying work task on the MCWP configured with no production table and the manufacturer- and NIOSH-designed production tables. The bricklaying task required subjects to grasp, with their dominant hand, one brick, from a stack of bricks, which were located behind their back either on the production table or on the surface of the MCWP (i.e. step deck condition) (Figure 2). Simulated motions were used to mimic application of mortar to the bricks. With their non-dominant hand, they then placed five bricks in a row followed by an additional 3 rows of 5 bricks on top of the first row using Velcro tape on the top and bottom of each brick to hold it in place (Figure 1). Each trial consisted of subjects laying 20 bricks with a self-selected work pace.

There was a total of 3 production table configurations (conditions). The first condition was of a typical MCWP mason setup with a “step-down” section which is located below the surface of the working deck (the step-down section was connected to outriggers under the main platform) (Figure 6). The worker stood on the step-down section of the working platform while performing their work activity. The other 2 conditions involved the worker standing level with the working platform and using the two different production table intervention devices that were designed to improve worker posture/ergonomics and efficiency (Figure 7).

Using the production table configurations (Figures 2 and 7) enabled the workers to perform work tasks while standing on the main deck level. This work configuration minimized tripping hazards as compared to the step-down production table configuration shown in Figure 6.

2.7. Data Processing and Analysis

Signals from the force plates and reflective markers were recorded simultaneously using the Vicon Nexus version 2.6 software. Trunk ranges of motion were defined as the maximal amount of angular movement in the sagittal, frontal and transverse planes during the work task activity. The peak ground reaction forces were obtained in X, Y and Z coordinates respectively in the medial-lateral (ML), anterior-posterior (AP) and vertical (Z) directions, which were then normalized to each participant’s body weight. Trunk sway related variables were derived from force plate data. Overall sway velocity was defined as the total travelled distance of the center of pressure (COP) during each task performance divided by its corresponding total time of performance. The associated COP velocities in the medial-lateral direction (V ML) as well as anterior-posterior direction (V AP) were also calculated based on the total COP travelled distance in each direction. To represent body sway, a 95% confidence circle and confidence ellipse of the COP sway area were calculated (Zolghadr et al., 2018).

2.8. Statistical Analysis

For trunk range of motion, body sway and impact force, repeated measures analyses of variance (ANOVAs) were performed using the SAS MIXED procedure to evaluate the effect of different experimental conditions. In this mixed model approach, the fixed effects included working condition and flexibility; and the random effect included the participant effect. The analysis also included an interaction term of working condition by flexibility in the final model. Note that for trunk range of motion data, the working condition included three levels: (1) no table (conventional), (2) manufacturer straight-shaped production table, and 3) NIOSH L-shaped production table. However, for body sway and impact force data, the working condition included only two levels: (1) no production table (conventional) and (2) production table (including the manufacturer straight-shaped and NIOSH L-shaped tables since both had the same working platform configuration condition.)

For post-hoc multiple comparisons, the Bonferroni-adjustment was used to determine significant differences among different experimental conditions. All significance levels (α) in hypothesis testing were set at 0.05 for this study.

Statistical Analysis System (SAS) software (SAS Institute Inc., Cary, NC, USA) was used to perform all data analyses. Prior to any statistical testing, the normality assumption was examined using a probability plot.

3. Results

The type of production table configuration (i.e., manufacturer straight-shaped and NIOSH L-shaped design) had significant effects on the trunk range of motion (ROM) in all three planes: Sagittal, Frontal and Transversal ($p<.0001$, Table 1). The amount of flexibility used with the production table showed no significant effect for both the spinal and pelvis ROM in any plane ($p>.05$, Table 1). Post hoc analysis found that the “L” shaped production table resulted in the lowest ROM in all three planes (frontal, transverse, and sagittal planes) as compared to the manufacturer straight-shaped production table condition and the conventional step-down use condition (Figure 8). Use of the “L” shaped production table resulted in a significant improvement of ROM in all three planes of spine and pelvis as compared to the conventional step-down use configurations; and in all three planes for spine, and frontal and transverse planes for pelvis as compared to the manufacturer straight-shaped production table (Figure 8). There was no observed significant difference of ROM in the transverse plane for spine and pelvis between the conventional step-down and the manufacturer straight-shaped production table use configurations (Figure 8).

Body sway data showed that both sway velocity and sway area were significantly reduced when using either production table as compared to the conventional platform configuration (Tables 2 and 4, Figure 9). However, no significant differences were observed between flexibility levels (Table 2). Stepping down from either the manufacturer straight-shaped or the NIOSH L-shaped production table demonstrated the same working platform configuration condition.

The impact force generated when stepping down to the work platform in the conventional platform configuration was significantly higher than the impact force observed with the walking forward activity when the working platform was configured with the production tables (Tables 3 and 4, Figure 9). This observation was obvious and expected. No significant difference was observed from different flexibility factors (Table 3).

Discussion

Work-related musculoskeletal disorders (WMSD) cost U.S businesses approximately $13.11 billion annually. Falls to the same level and falls to a lower level cost U.S businesses approximately $15.36 billion annually, accounting for 23.7% and 27.7%, respectively, of the overall national burden in 2018 (Liberty Mutual, 2019). The back is the primary body part most affected by WMSDs in the construction industry (CPWR, 2018) and the costs associated with back pain treatment is the most expensive in the United States (Dieleman et al., 2016). These types of injuries and their associated discomfort may develop into chronic health problems and can sometimes lead to permanent disabilities (Marcum et al., 2017; West et al., 2016). WMSDs are a significant cause of chronic functional impairments and permanent disability for construction workers. One segment of this workforce, brick-and block-layer masons, the focus of this study, experience a significant number of WMSDs, and interventions and engineering redesigns for the reduction of back injuries are evidently needed for these workers (Boschman et al., 2012, 2015; Hess et al., 2012).

Results of this study found that using the MCWP configured with a production table, especially the L-shaped design, significantly reduced the range of trunk motion during a simulated bricklaying task vs. using the MCWP in the conventional step-down configuration. Previous studies have demonstrated that excessive amounts of trunk motion increase spinal compression and shear loadings which may lead to lower back pain (Marras, 1993, 2004; Norman et al., 1998; Ning et al., 2014; Pan et al., 1999[a], 1999[b], 2003). The use of either production table designs (manufacturer straight-shaped and NIOSH L-shaped) enabled the bricks to be located closer to the workers' torso therefore reducing trunk movements. In this study, using a production table with the MCWP proved to be an effective intervention tool to help reduce trunk range of motion and the associated risk of back-related injuries for masons performing a bricklaying task. A study involving manual materials handling tasks in a chemical plant also found that the use of a mobile, elevating, adjustable work platform was an effective intervention tool to help prevent WMSDs (Chao et al., 2018). Other studies in agriculture (Kato et al., 2006; Jin et al., 2009), fishing (Mirka et al., 2011), mining (Dempsey et al., 2018), retail (Bajaj et al., 2006; Draicchio et al., 2012) and construction (Jia et al., 2011; Kim et al., 2008; Pan et al., 2006; Pan et al., 2012[b]) have also demonstrated the effectiveness of engineering design interventions in reducing back injury risks and improving worker productivity (Nussbaum et al., 2009). Engineering design interventions, such as the use of a production table, can be used to reduce the risk of WMSDs to workers using MCWPs.

Falls are the number one cause of fatalities in the construction industry (CPWR, 2018). Fatal falls from scaffolds are the third leading source representing 14.8% of these fatalities (CPWR, 2018); an increasing trend for using MCWPs in the scaffolding industry has been identified (Wimer et al., 2017). In the scaffolding industry, there are some interventions (e.g., toe boards and handrails) that have been demonstrated to be effective for preventing fall-related injuries (Hara, 2016; Min et al., 2012, 2014; Rubio-Romero et al., 2015).

In our study, workers experienced smaller whole-body sway after stepping onto a MCWP configured for use with a production table (i.e., manufacturer straight-shaped or NIOSH L-shaped table). This result was statistically significant among all tested postural sway related variables. Reduction of sway velocity was clearly observed in both anterior-posterior and medial-lateral directions, indicating an improvement in whole-body balance in both directions.

We also observed significantly smaller impact forces in both the X and Y shear directions and the vertical Z direction using a MCWP configured for use with a production table. The reduction of sway area was the most significant among all sway-related variables. Based on Zolghadr's study (2018), both the 95% confidence circle and 95% confidence ellipse were reduced by more than 80% showing a clear and significant improvement in standing balance. Previous studies have shown that body sway is a direct indication of body balance and is associated with the risk of falling (Bagchee et al., 1998; Bhattacharya et al., 2003; Chiou et al., 2000, 2008; Kincl et al., 2002; Pan et al., 2009, 2017).

The construction workforce is aging, and when older workers are injured, their fall and overexertion injuries tend to be more severe, and their compensation and rehabilitation costs higher (Dong et al., 2011; Sokas et al., 2019). The aging of the U.S. construction workforce requires immediate attention and improved interventions to prevent fatal and nonfatal injuries for older workers (Dong et al., 2019; Sokas, et al., 2019). Due to fall and MSD injuries, many construction workers experience physical limitations or pain levels that force them to retire in their mid-50s, limiting their income-earning potential and negatively impacting the quality of their retirement life (Carnide et al., 2011; Welch et al., 2010; LeMasters et al., 2006). It has been suggested that aging results in reduced sensorimotor functions, muscle weakness in the legs, increased reaction time, and increased body sway (Lord et al., 1991; Teasdale and Simoneau, 2001). These functional deteriorations are all important factors associated with postural instability and overexertion which may lead to increased risks of loss of balance, fall incidents, and musculoskeletal injuries at construction worksites when working at heights (de Zwart et al., 1997; Hildebrandt, 1995; Pan et al., 2017). Another study (Dong et al., 2011) indicated that the fatality rate caused by falls is significantly higher for aging construction workers than younger counterparts in various construction trades, including masons. Therefore, using effective and improved intervention techniques (e.g., a production table) associated with MCWPs and helping construction workers maintain good posture/balance at heights may help to reduce fall and overexertion hazards (Pan et al., 2018; Wimer et al., 2017).

Two studies (Viester et al., 2012, 2015) have indicated that the effectiveness of interventions designed to reduce WMSDs for construction workers were limited without incorporating psychosocial factors. Future studies could incorporate measures of psychosocial factors related to the use of production tables. Despite not evaluating psychosocial factors in this study, the usefulness of both the manufacturer straight-shaped and NIOSH L-shaped production tables to reduce risk factors for WMSDs and falls was clearly demonstrated. Future studies will be needed to properly validate the effectiveness of production tables for reducing the risks of falls and back injuries associated with using MCWPs and other emerging elevated work platform equipment at worksites (Pan et al., 2018). We believe this study to be the first research study specifically designed to evaluate falls and WMSD interventions for a targeted segment of the construction workforce (bricklayer masons) who are most commonly associated with the use of MCWPs.

Results of this study show that the flexibility factor did not exhibit significant influence on any of the measured dependent variables. It was expected that the flexibility factor would not affect body range of motion while performing the bricklaying tasks. Therefore, due to the nature of the step-down task, the results of this study show that flexibility factors associated with weight would not significantly affect postural-sway or back-injury hazards. However, different from our expectation, the flexibility factor did not significantly impact the motion- and sway-related factors. These results were possibly due to the small number of dampers (currently only 4 dampers) and their capacities (650 pounds or 236 kilograms) used in our study (Figure 3). Reducing the stiffness of the dampers on the simulated workstation may generate more flexibility and possibly produce “bottoming out effects”. This may more accurately mimic elevated conditions of a MCWP which would allow for a more unstable condition to be simulated and studied (Steffan and Moser, 1996; Stewart, 2000). The measurement of MCWP stiffness was conducted at a 1-foot elevated height, which is almost the highest stiffness value for the selection of the dampers. The NIOSH research team selected this lower height (less than 10 feet or 3 meters) which contributed to the majority of nonfatal fall injuries and 46% of fall-related incidents (CPWR, 2018). Future studies should include conditions when the work surface has higher flexibilities (i.e., less stiff dampers) to further evaluate the flexibility effects. However, this study’s focus was on the use of production table interventions for reducing the risk of both back injuries and postural instabilities; flexibility measurement was not the main focus of this study.

The current study has several limitations. First, in order to standardize the testing procedure, all subjects in this study were required to perform bricklaying tasks using one technique and one type of brick. Also, the results of this study cannot be generalized to the process of installing other type of materials (e.g. stone, glass, metal sidings etc.). Second, the influence of using the straight-shaped or the L-shaped table on bricklayer and blocklayer mason’s workflow and the associated productivity were not tested. Based on the trunk kinematics results of this study, it is suspected that using either the manufacturer designed or the NIOSH production table could enhance productivity by reducing trunk motion and potentially the associated muscle fatigue. However further analysis is required to confirm this conjecture.

Conclusions

Results of this study found that use of either the manufacturer designed straight-shaped production table or the NIOSH designed L-shaped production table significantly reduced postural-sway hazards while working on a MCWP as compared to using the MCWP in its conventional step-down use configuration.

Results of this study also found that both production tables significantly reduced some key risk factors that might associate with back injury hazards for bricklaying masons using a MCWP.

In the future, additional experimental data collected during this study, including gait/step characteristics (e.g., speed, step width and stride length) will be analyzed to focus on behavioral modifications that workers adopt when working at heights on a MCWP.

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Figure 1.
A mason worker performing the simulated bricklaying task on the workstation equipped with the manufacturer straight-shaped production table and simulated wall

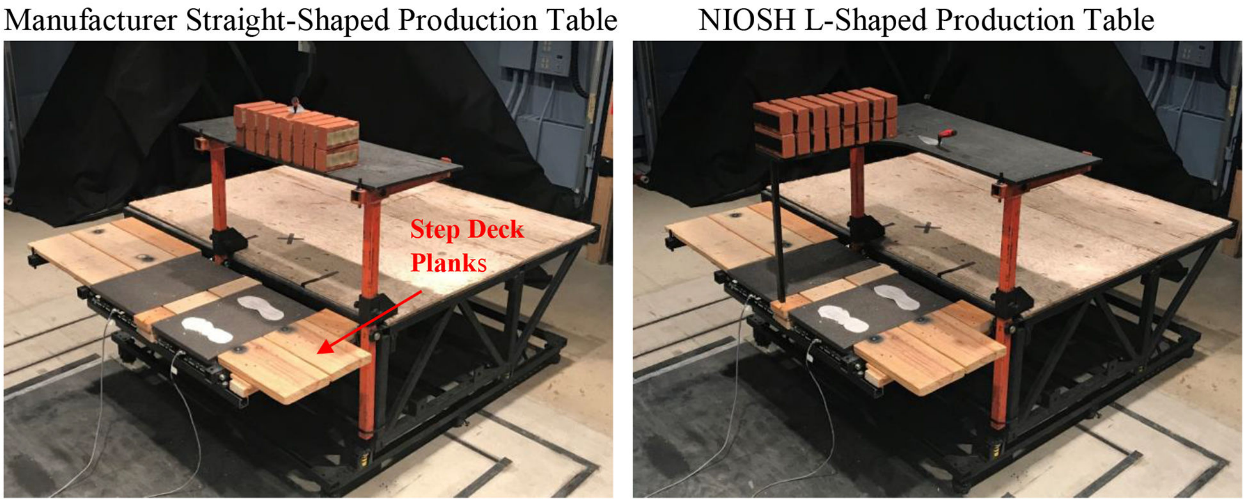

Figure 2.

Simulated workstation equipped with two production table designs and the Bertec force plates, with feet position markers, configured for the beginning of the bricklaying task

Figure 3.
One of the four extreme mount spring-dampers exhibiting a stiffness of 520 pounds (236 kilograms) per 0.75 inches (1.9 centimeters) of compression

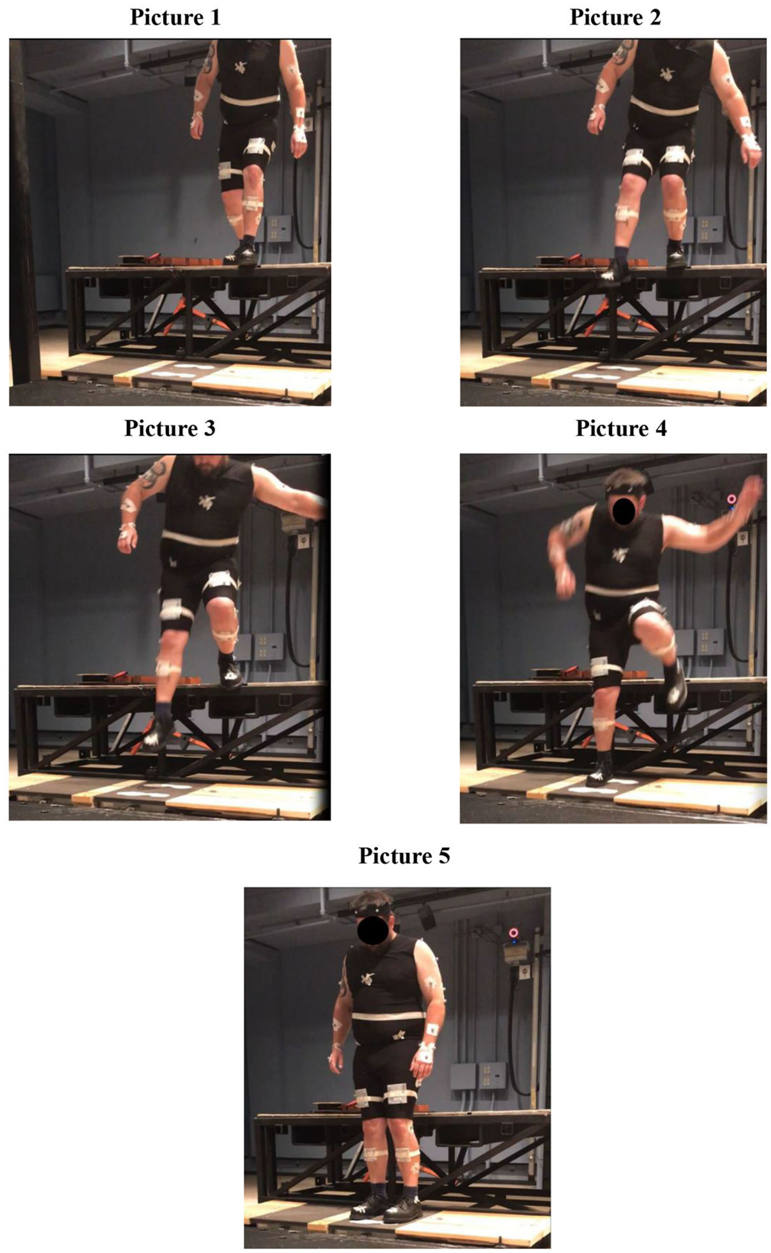

Figure 4.

A masonry worker performing the simulated stepping down task (Pictures 1 to 5) from a MCWP onto the step deck to get into position for doing the bricklaying task

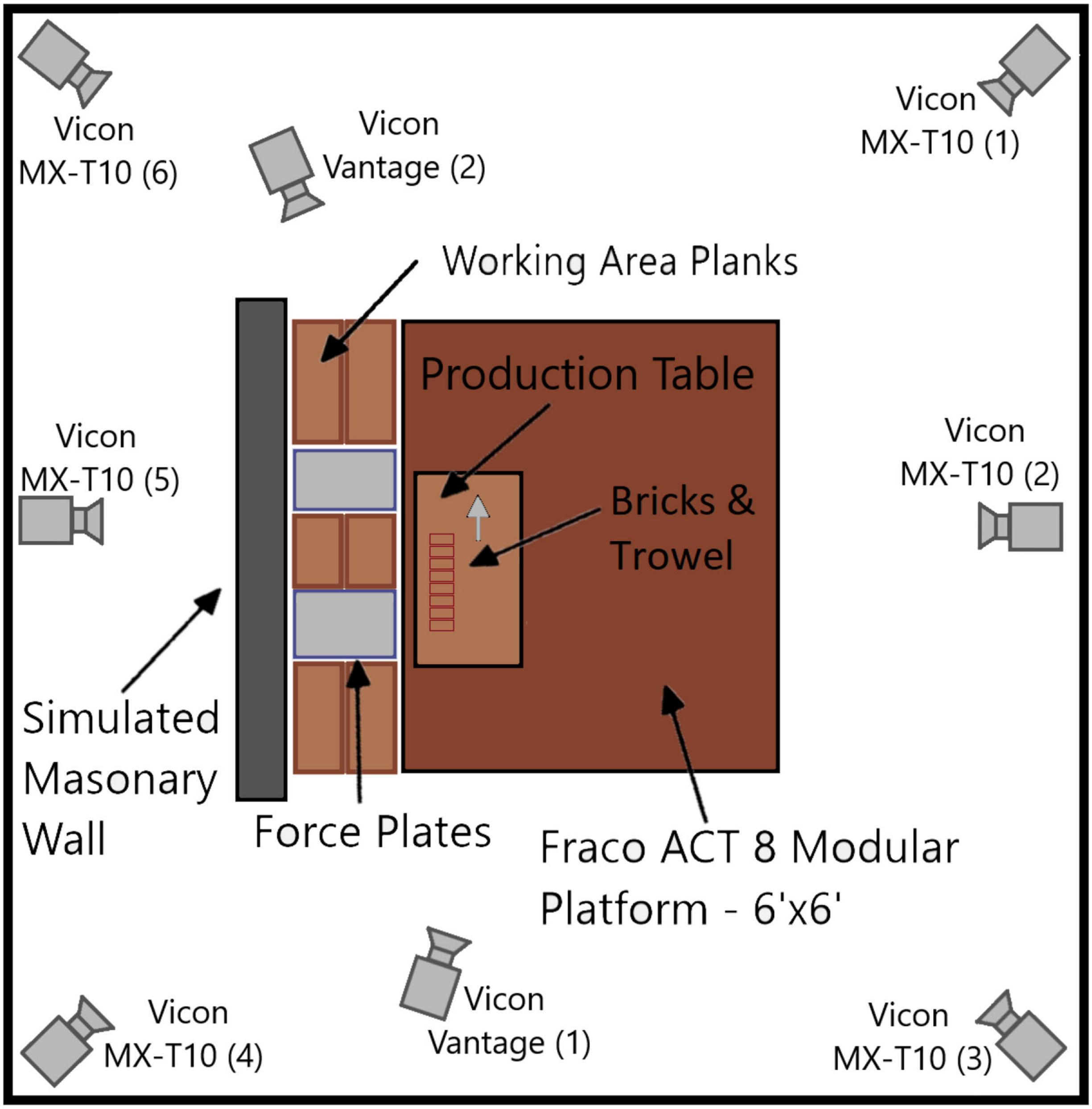

Figure 5.

A layout of the experimental setup including the location of Vicon cameras, Vantage cameras, the Bertec force plates, and top view of the production table.

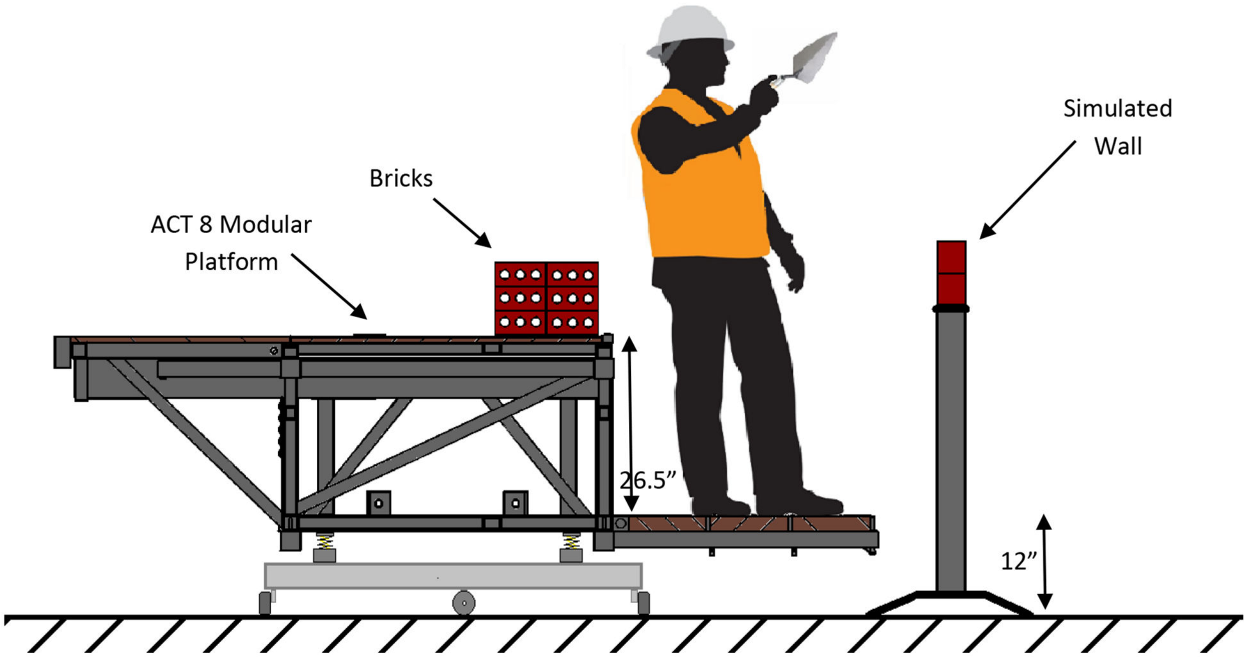

Figure 6.
MCWP in the step-down work configuration with the adjustable spring-dampers.

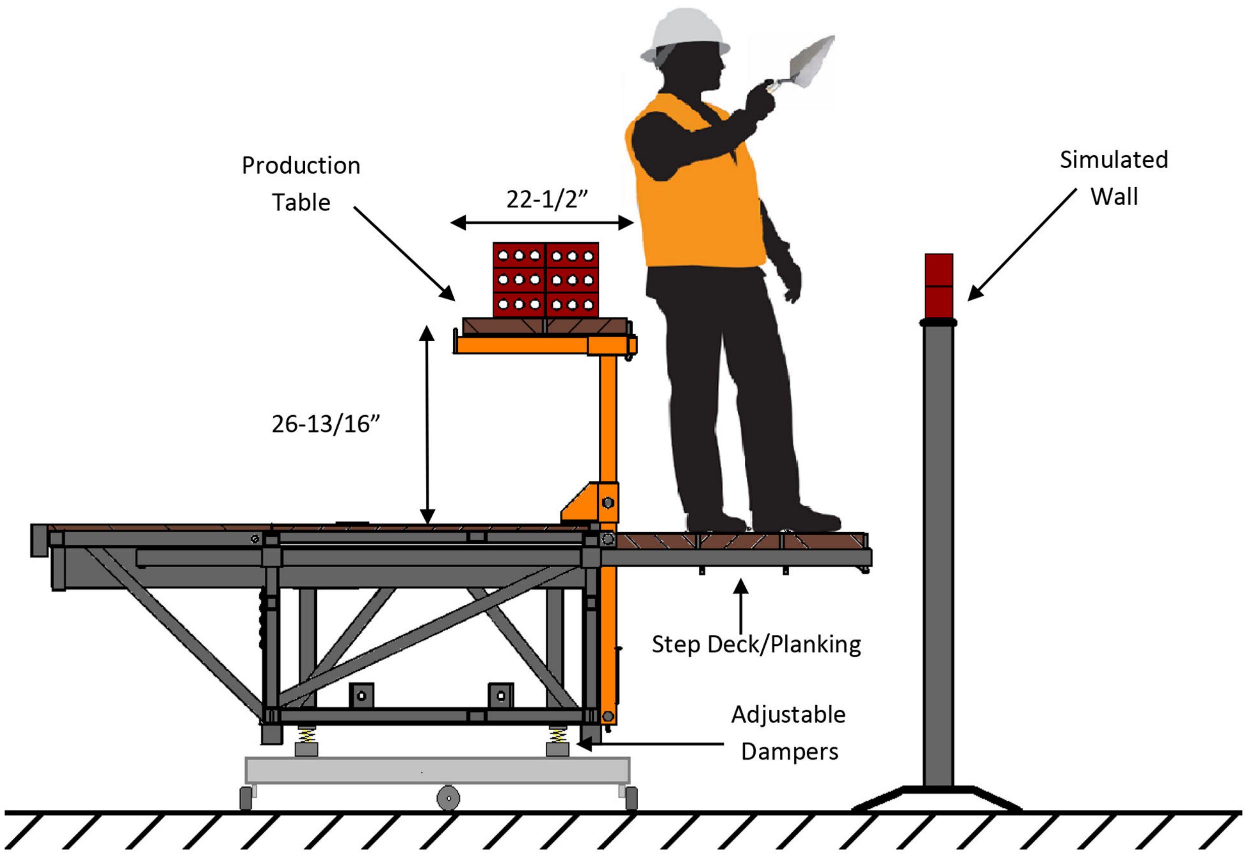

Figure 7.
MCWP in the production table work configuration with the adjustable spring-dampers.

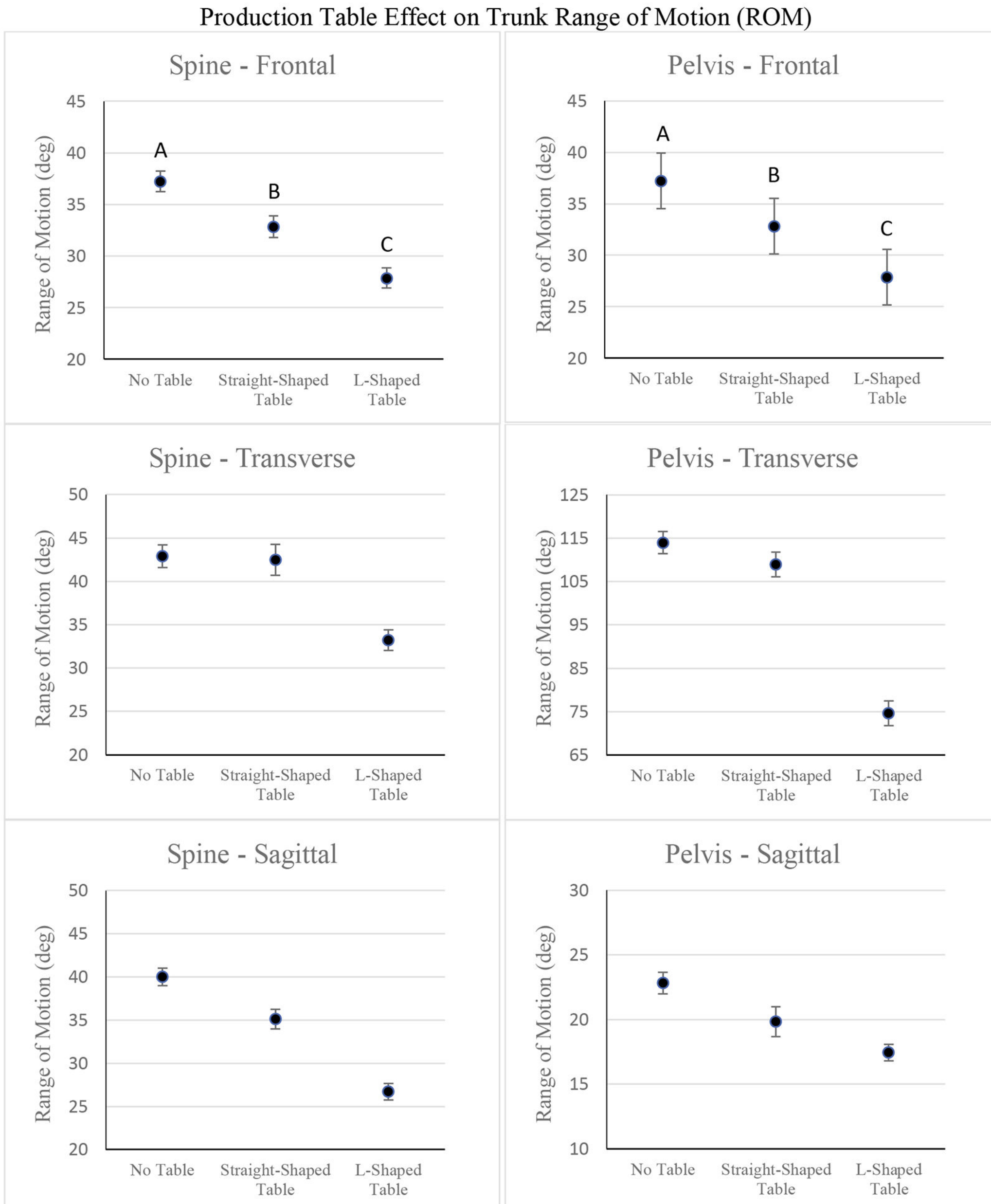

Figure 8:

Use of L-shaped table decreased ROM significantly when compared to "No-Table" use (all three planes of spine and pelvis) and straight-shaped production table (all except sagittal plane of pelvis). Use of both production tables also reduced ROM significantly for frontal and sagittal planes of spine and pelvis when compared to "No-Table" use. Note that different letters denote significantly different least square means. Vertical bars in each graph represent standard errors.

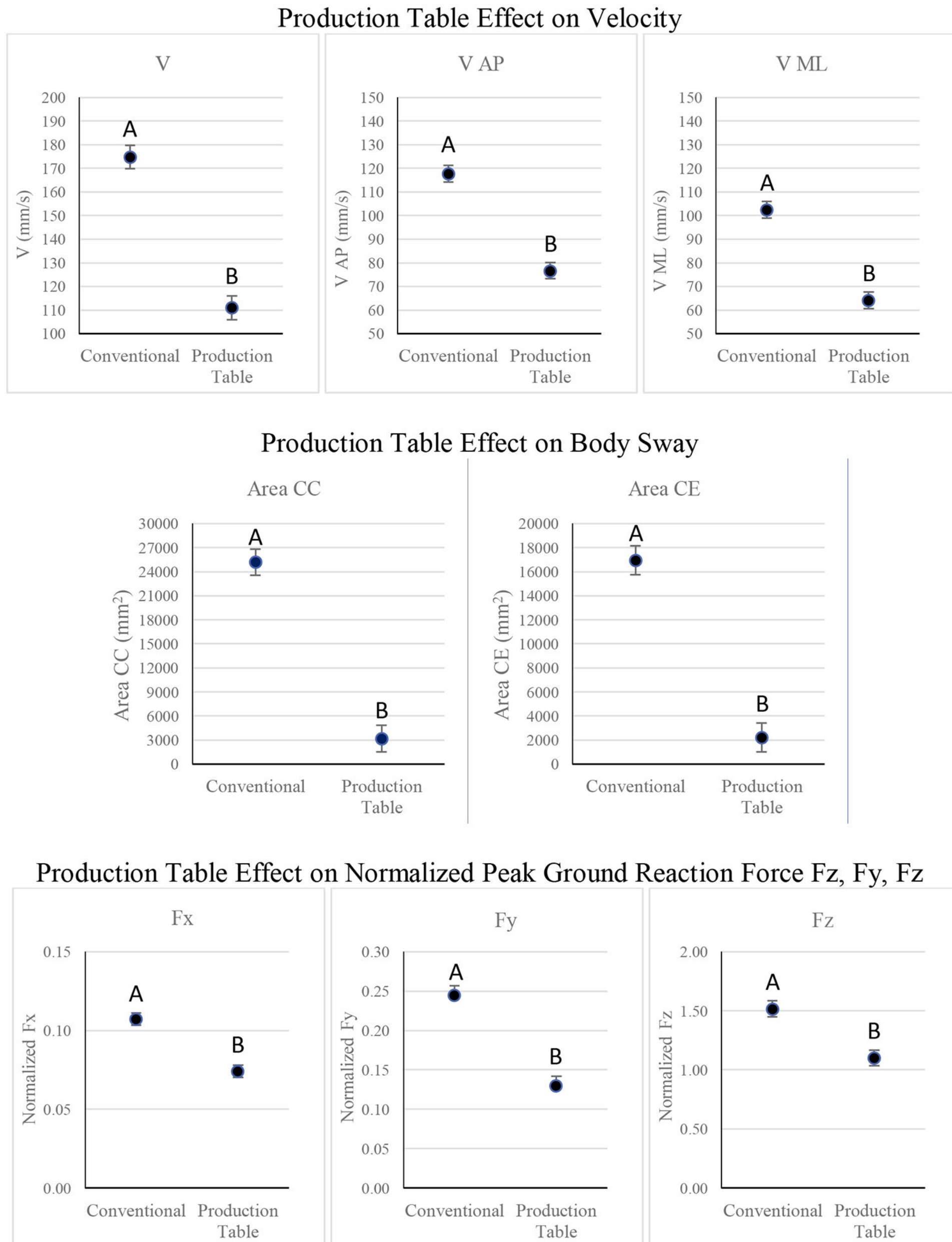

Figure 9:

Use of production table significantly reduced the velocity (V: velocity, V AP: Velocity from Anterior-Posterior, V ML: Velocity from Medial-Lateral); body sway (Area CC: area of the 95% confidence circle, Area CE: area of the 95% confidence ellipse), and peak ground reaction forces (Fx, Fy, Fz - normalized to participant's body weight). Note that different letters denote significantly different least square means. Vertical bars in each graph represent standard errors

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Table 1:

Repeated measures analysis of variance results for trunk range of motion – p-values

	Spine			Pelvis		
Experimental Condition	**Frontal**	**Transverse**	**Sagittal**	**Frontal**	**Transverse**	**Sagittal**
Production Table (Straight-Shaped Table vs. L-Shaped Table vs. No Table)	**<.0001** *	**<.0001** *	**<.0001** *	**<.0001** *	**<.0001** *	**<.0001** *
Flexibility (Maximum vs. Minimum)	0.44	0.37	0.66	0.62	0.43	0.59
Production Table * Flexibility	0.75	0.70	0.17	0.66	0.21	0.43

* indicates statistically significant effects

Table 2:

Repeated measures analyses of variance results of sway data – p-values

Experimental Condition	V	V AP	V ML	Area CC†	Area CE†
Production Table Use (Yes, No)	**<.0001** *	**<.0001** *	**<.0001** *	**<.0001** *	**<.0001** *
Flexibility (Maximum vs. Minimum)	0.58	0.07	0.92	0.99	0.77
Production Table Use * Flexibility	0.78	0.44	0.83	0.85	0.74

† Area CC: area of the 95% confidence circle; Area CE: area of the 95% confidence ellipse

* indicates statistically significant effects

Table 3:

Repeated measures analyses of variance results of normalized impact force – p-values

Experimental Condition	Normalized		
	Peak Fx	**Peak Fy**	**Peak Fz**
Production Table Use (Yes, No)	**<.0001** *	**<.0001** *	**<.0001** *
Flexibility (Maximum vs. Minimum)	0.92	0.82	0.95
Production Table Use * Flexibility	0.83	0.57	0.95

* indicates statistically significant effects

Table 4:

Mean and standard deviation of peak ground reaction forces and sway related variables by type of production table.

Conditions		**V (mm/s)**	**V AP (mm/s)**	**V ML (mm/s)**	**Area CC (mm^2)**	**Area CE (mm^2)**	**Fx (N)**	**Fy (N)**	**Fz (N)**
Conventional	Mean	179.8	120.4	105.6	25207	16979	91.6	209.6	1355.3
	Std	43.3	31.6	31	17485	13317	33.6	81.4	512.3
Production Table	Mean	113.5	78.2	64.6	3180	2215	60.4	110	922.2
	Std	22.2	16.5	13.2	2581	1382	16.5	39.3	246.9