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Comparison of stoop versus prone postures for a simulated agricultural harvesting task

Robert H. Meyer, Robert G. Radwin*

University of Wisconsin, 1513 University Avenue, Madison, WI 53706, USA

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Abstract

Physical and psychophysical differences between working in the stooped and prone postures were compared while performing a simulated agricultural harvesting task for 30 min. Fifteen male subjects participated. The measures used to compare the two postures included perceived discomfort, electromyography (EMG), and heart rate (HR). Average hamstrings localized discomfort (0–10 scale) was 6.17 (SD = 2.9) for the stoop posture and 0.67 (SD = 1.29) for the prone posture. Erector spinae and hamstring EMG RMS increased 68% and 18%, respectively, while mean power frequency for the hamstrings decreased 13% for the stoop task. Mean power frequency for the middle trapezius muscle decreased in both postures (stoop 4.13%, prone 3.79%). Average heart rate during the last work cycle was 35% greater than the resting heart rate for the stoop posture while average heart rate was 17% greater for the prone posture. Subjects worked on the prone workstation without rest during the 15 min work simulations with less discomfort, no localized fatigue in the back or leg muscles tested, and lower working heart rates than subjects working in the stoop posture.

Keywords: Agriculture; Posture; Fatigue

1. Introduction

Stoop labor is often necessary in non-mechanized agricultural field work. Certain tasks, such as hand harvest, have not been easily mechanized. Workers performing these tasks in the US are typically paid piece-rate and may resist ergonomic changes in the workplace that might appear to negatively influence productivity (Miles and Steinke, 1999). The nature of hand labor in agriculture exposes farm workers to a variety of musculoskeletal risk factors resulting in sprains, strains and back injuries (Villarejo and Baron, 1999). Farm workers also report a greater than average incidence of low back pain, upper limb complaints, sprains and strains, and back injuries that result in lost work (Osorio and Beckman, 1998; Novello, 1991; US Department of Labor (DOL), 2002).

Previous attempts to remedy prolonged bent and stoop postures originate in the 1950s. One study estimated overall energy expenditure rate was greatest when standing bent over, while the least practical posture for agricultural work was prone (Samann, 1970). Different stooped postures have been quantified as well, showing that bending and kneeling are preferred if one can support part of the body weight on one of the hands (Vos, 1973). More recent studies have demonstrated the efficacy of a seated workstation while working at ground level (Van Dieen et al., 1997). All of these previous studies have concluded that even though the alternatives were shown to reduce energy expenditure and strain compared to no support or stooping, the "recommended" postures (i.e. seated, kneeling) were still considered ergonomically deficient.

Prone workstations provide an alternative to stooping; they place the body in a neutral spinal posture yet still allow workers to reach crops growing at ground level. Some prior research has studied the prone workstation from a feasibility and work performance aspect. These studies focused on mechanical aspects of the design (locomotion, etc.) or general productivity. Starting in the 1960s, presentations appeared in the Western US

*Corresponding author. Tel.: +1 608 263 6596; fax: +1 608 265 9239.
E-mail address: radwin@engr.wisc.edu (R.G. Radwin).

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horticultural associations regarding prone mobile strawberry picking platforms (Biringer, 1963). This study confirmed the productivity and preference of workers for the prone posture.

During the 1980s, two papers were published by the American Society of Agricultural Engineering (ASAE) discussing productivity and prone workstations. An adapted tobacco tool carrier, modified to allow a worker to lie prone, did show an increase in productivity of 25.7% over traditional harvest methods (Swetnam et al., 1984). Worker ($n = 4$) comfort was characterized with the statement that the workers ''preferred the prone workstation over traditional''. Another paper reported ''nearly double harvest rate and speed compared to conventional hand harvesting'' (Theriault, 1988).

Recent studies in Europe have used electromyography (EMG) to compare muscle activity within different prone designs and between postures and alternative labor aids. A German researcher discovered less muscle activity in the trapezius muscles with continuous upper torso support (Rullman and Kliesinger, 2003). Finnish researchers studied a variety of harvest aids for strawberry picking including two prone workstations (Matilla et al., 2002). They found lowered heart rate, improved picking speed and less reported discomfort than for traditional, kneeling and seated labor aids. Although prone posture workstations appear to have ergonomic benefits, there is no quantitative data regarding the potential negative aspects, such as shoulder and neck fatigue with prolonged use. This could arise from repetition neck extension or shoulder flexion during reach that are done in different positions than in stooped work.

Table 1
Subject demographic information

	Mean	SD	Range
Age (years)	23.0	37	19–33
Height (cm)	179.8	9.6	167.6–193.0
Weight (kg)	77.1	11.1	63.5–99.8
Body Mass Index (BMI)	23.9	3.25	20.7–32.1

The current study investigates localized muscle fatigue related to stoop and prone postures. This study also compares perceived discomfort and heart rate between the traditional stoop postures with a prone workstation in a laboratory experiment.

2. Methods

Fifteen healthy, non-smoking male students were recruited from the University of Wisconsin—Madison as subjects for this experiment. Due to the physical nature of the experimental conditions, smokers were excluded to reduce confounding related to back pain. Subject demographics are listed in Table 1.

All subjects reported they were free from back pain or treatment for at least the previous 6 months, and none were actively involved in agricultural tasks during the protocol. Participation was voluntary and subjects gave written informed consent prior to participating. The Human Subjects Committee of the University of Wisconsin—Madison's Health Sciences Institutional Review Board approved the study. All study components were conducted in the Occupational and Biomechanics Laboratory at the University of Wisconsin—Madison.

Subjects were randomly assigned to each starting posture (stoop or prone) and completed the tasks on separate days to avoid carryover discomfort or fatigue (Fig. 1). A 60.5 cm wide conveyor simulated the agricultural work, moving at 2.13 m/min with five 4.5 cm holes/row spaced 10 cm apart in an offset pattern. Subjects were instructed to move balls from a collection bin in each hand and position them into any open hole on the conveyor belt. After traveling 60.5 cm, all balls dropped through the conveyor and into the collection bin. The task was done in two 15-min work periods, with a 5 min period for EMG signal collection in between. The task simulates the arm and hand motions, pinch grips and loads associated with a picking or planting task. The conveyor provides a consistent reach pattern and frequency similar to previous agricultural simulations which used playing cards (Van Dieen, 1997) and pulling

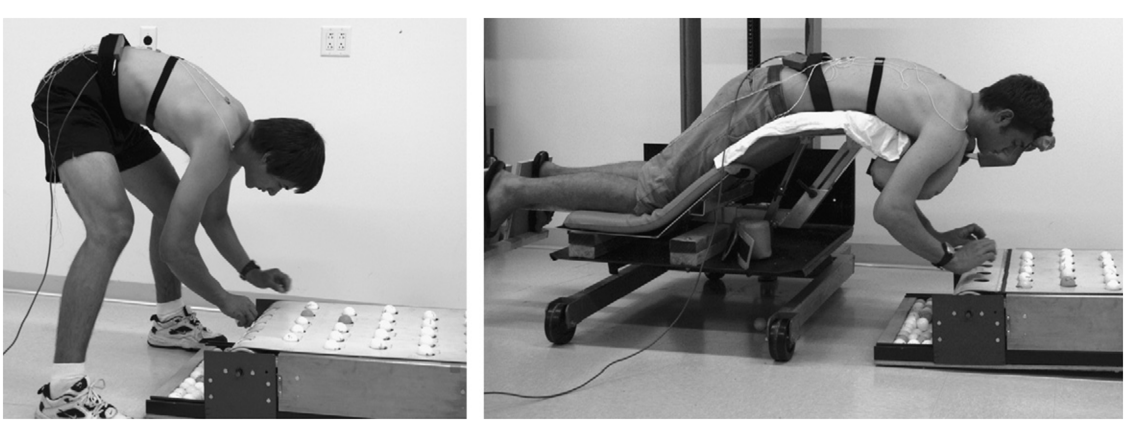

Fig. 1. Stoop posture (left) prone workstation (right) with conveyor apparatus.

small PVC sections from spring clamps (Rullman et al., 2003) to simulate an agricultural task.

The stoop task was performed for a 4:1 work/rest ratio where subjects were asked to work stooped for 2 min, and then take a 30 s break during 15-min work periods. The prone task was done with the shoulders positioned directly above the ball collection area. Prone task subjects worked continuously for each 15-min period. A visual and auditory pacing signal was provided. Since the task was performed in a static stoop, rather than the dynamic posture and movement associated with field labor, subjects were allowed to change postures during the 30 s rest period. Pilot subjects were not able to perform the stoop task without periodic rest breaks.

The commercially available prone workstation (Mapro Projekt, Sweden) was mounted to a hydraulic platform for height adjustment between subjects. The prone workstation adjusts for worker anthropometry by sliding the (45 cm × 60 cm) torso support out of the telescoping center support. The center support has separate leg supports with the thigh supported at a 45° angle from the horizontal shin. A sliding footrest is also provided to maintain posture. Adjustment of the torso angle is accomplished with two telescoping support pieces, giving a height range from 25 to 40 cm above the level of the horizontal leg supports. Shoulders are supported with an additional stainless-steel crosspiece that can be bent to accommodate reaching to the center of the body. A bendable, padded forehead rest is provided to reduce the load on the neck muscles. All contact areas of the prone workstation are covered by pads made from 5 cm thick polyurethane foam covered in vinyl.

The timing, ball placement rates and work/rest ratios were estimated using Multimedia Video Task Analysis (MVTA) software to conduct a time study of field workers picking strawberries in the stoop posture. The work pace for stoop labor was established using work/rest ratio based on 100% success rate at filling the conveyor holes. The resulting difference in the work pace corresponds to past studies of prone workstations which demonstrated between 20% and 30% productivity increases (Swetnam et al., 1984; Theriault, 1988).

2.1. Data collection and analysis

A modified 0–10 visual–analog scale was used to assess the perceived discomfort relative to strenuous exercise. The anchors were 0 for "no discomfort" and 10 for the "most discomfort." Discomfort was defined as pain, tingling and soreness. Subjects were asked to complete the discomfort scale prior to EMG electrode placement. Immediately following the second 15-min task, subjects were asked to assess their level of discomfort while performing the task.

EMG signals were measured using a Measurement Systems, Inc. EMG amplifier system with reusable Ag–AgCl leads (5 mm diameter). Electrodes were located following the standards for placement and spacing developed by the European SENIAM project (Freriks and Hermens, 2000). Muscle activation, posture and load used for each muscle group is summarized in Fig. 2. The middle trapezius muscle was activated in the prone posture using a 1.36 or 2.27 kg hand weight by extending the arm; thumb up and in line with the shoulders for 15 s duration. The longissimus thorasus muscle (erector spinae) was activated by having the subjects lay prone on the examination table, hands to the side, palms facing upward and performing a back extension so the ribcage was lifted off the table and held for 15 s duration. Hamstring activation was conducted in the prone position using 1.36 or 2.27 kg ankle weights. A manual goniometer was used to set the leg position at 30° from horizontal for 15 s.

EMG signals were measured throughout the duration of the exertion for later analyses. A National Instruments 6024E DAQ-card in a laptop computer was used for analog to digital conversion of the EMG signal, which was sampled at 1000 samples/s and filtered using a digital notch filter to remove 60 Hz noise. The RMS and power spectrum were calculated.

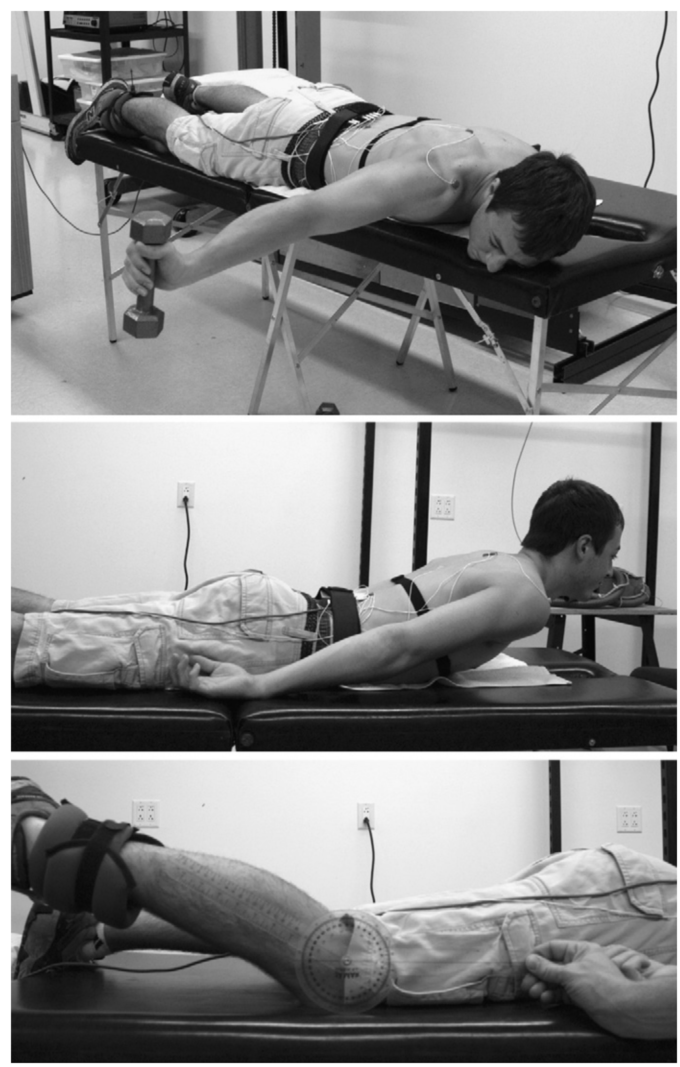

Fig. 2. Muscle contraction positions for EMG collection. Trapezius (left), Erector spinae (center), Biceps femorus (right).

Heart rate was measured using an athletic training monitor (Polar Model 720i) and the data was downloaded to a laptop computer. Heart rate was based on a 0.2 samples/s sampling rate. Resting heart rate was calculated for the period when subjects were prone during electrode placement. The percent change from average resting heart rate (recorded while lying prone) to the final average working heart rate (averaged over the last 15 min working period) was calculated for each posture. Statistical analysis used a general linear model for main and interaction effects, within subject and between postures.

3. Results

Perceived localized discomfort was assessed before, and immediately following the second 15-min work session. The outcomes for the left and right side were pooled. A paired sample t-test verified that there was no significant ($p > .05$) difference between responses for the right and left side of the body. Greater discomfort was reported for the stoop posture (Table 2) for most body segments on the self-reported diagram (Appendix A). Statistically significant ($p < .05$) differences (Fig. 3) were seen mainly in the lower back and lower extremity, with the greatest mean difference in the hamstrings (5.50).

The trapezius (trapezius transversalis) EMG RMS amplitude did not significantly increase ($p > .05$) over any of the work periods. The average mean power frequency decreased for both postures after the first 15-min work period by 4.13%, SD = 0.11 for the stoop posture ($F(2, 26) = 4.939$, $p = .015$) and 3.79% SD = 0.18 for the prone posture ($F(2, 28) = 3.767$, $p = .036$). The average EMG mean power frequency after the second work period did not change ($p > .05$) for either posture.

Table 2
Mean discomfort for stoop and prone postures (significant $p < .05$ indicated with an asterisk, non-significant in italics

$N = 14$	Stoop		Prone		Mean dif.
	Mean	SD	Mean	SD	
Hamstring*	6.17	2.926	.67	1.291	5.50
Knee (back)*	3.50	2.S47	.13	.352	3.37
Lower back*	4.27	3.035	1.20	1.897	3.07
Thigh (front)*	3.33	3.086	.40	.910	2.93
Knee (front)*	3.00	3.117	.17	.362	2.83
Calf (back)*	2.97	2.881	.33	1.047	2.63
Bottom of foot*	1.47	2.696	.07	.258	1.40
Shin*	1.40	2.384	.07	.258	1.33
Chest	f.20	2.513	.07	.258	1.13
Top of foot	1.20	2.981	.07	.258	1.13
Abdomen (front)*	1.07	1.668	.27	.799	.80
Back of neck	3.00	2.726	2.27	2.63?	.73
Triceps	.57	.980	.20	.561	.37
Front of head	.20	.561	.00	.000	.20
Middle back	2.00	2.507	1.80	2.396	.20
Front of shoulder	1.13	1.767	.97	1.232	.17
Front of forearm	.27	.799	.13	.352	.13
Back of forearm	.20	.561	.13	.352	.07
Back of shoulder	1.20	1.612	2.07	2.520	0.00
Back/upper shoulder (trapezius)	1.20	1.612	1.20	1.474	−.03
Front of neck	.67	1.799	.73	1.580	−.07

The erector spinae (longissimus) EMG RMS amplitude increased after the first work period for the prone posture. There was a 53.7% SD = 0.23 ($F(2, 26) = 15.784$, $p = .001$) increase in the EMG RMS amplitude for the stoop position, while the prone position EMG RMS decreased 5.59% SD = 0.15 ($F(2, 28) = .697$, $p > .05$) in the same timeframe. There was an additional increase of 9.45% between the end of the first work period and the end of the second work period for the stoop position (Fig. 4), however, this was not statistically significant ($p > .05$). Although both postures had a significant change from baseline to the first work period, the prone posture EMG RMS values for the erector spinae decreased from baseline to after the first work period, rather than increase as seen in localized muscle fatigue.

The hamstring (biceps femorous) EMG RMS increased 18.5%, SD = 0.15 ($F(2, 12) = 6.190$, $p = .029$) from the baseline measure for the stooped posture after the first work period. During the same time the prone posture EMG RMS amplitude decreased 5.29%, SD = 0.10, and it was not statistically significant ($p > .05$). Additionally, a decrease in the mean power frequency by 12.6%, SD = 17.15 ($F(2, 26) = 7.214$, $p = .003$) was observed after the first work period for the stoop posture. The 5.1%, SD = 18.08 ($F(2, 28) = 1.139$, $p = .335$) decrease for the prone posture was not statistically significant.

The heart rate increased 35.2% ($F(1,11) = 165.24$, $p < .001$) above the resting heart rate for the stoop posture, compared to a 16.9% ($F(1,13) = 71.803$ $p < .001$) increase for the prone posture. The mean difference between resting and working was 25.7 bpm for stoop and 12.5 bpm for prone.

The average percent of maximum working heart rate for stoop posture was 20.83% (range 4.8–30.7%) greater, where prone posture was 8.2% (range 2.7–17.8%) greater. A representative graph of heart rate during the final work cycle (Fig. 5) shows a steep drop in heart rate as the subject stands up during the rest phase. During prone work the heart rate was lower and less variable.

4. Discussion

Differences were observed for all three measures in favor of the prone posture. Perceived discomfort was greater in the low back and lower extremities when compared to traditional stoop methods and supports the findings of Matilla et al. (2002). The discomfort could be attributed to the prolonged static contraction of the lower back and hamstring muscle groups needed to maintain the stooped posture, with the hamstrings taking the majority of the stress (mean difference in reported discomfort of 5.51 on the 0–10 scale). In the field, the stress on the hamstring muscles might not be as extreme over the same time period

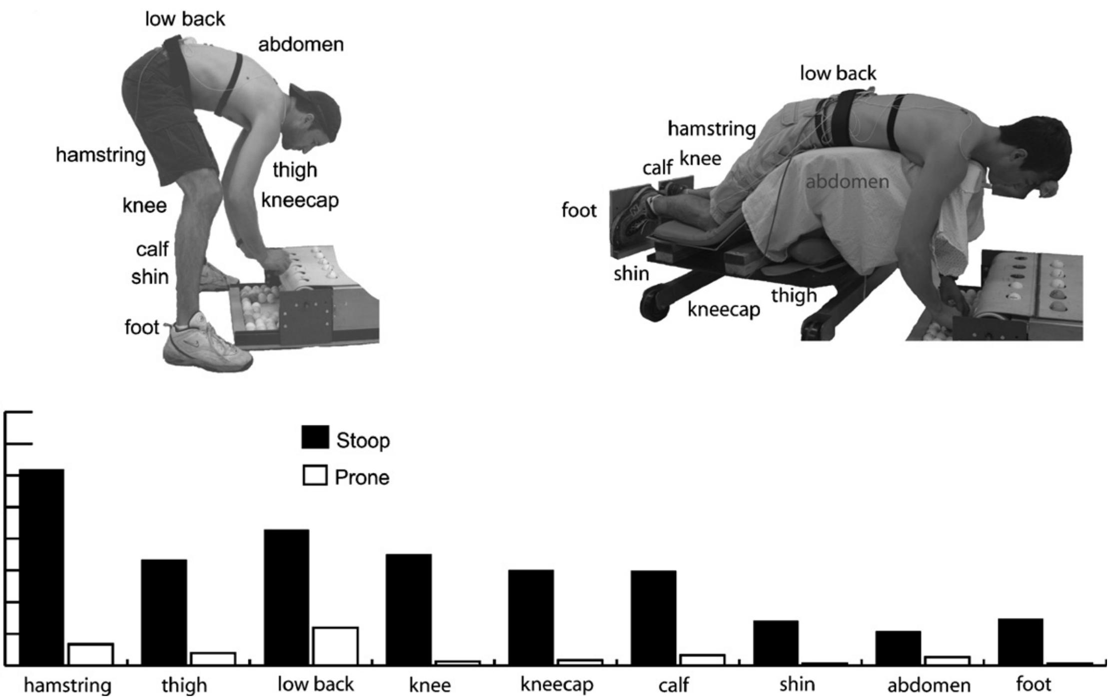

Fig. 3. Significant mean discomfort by body segment (0–10 scale) for stoop (left) and prone (right) posture.

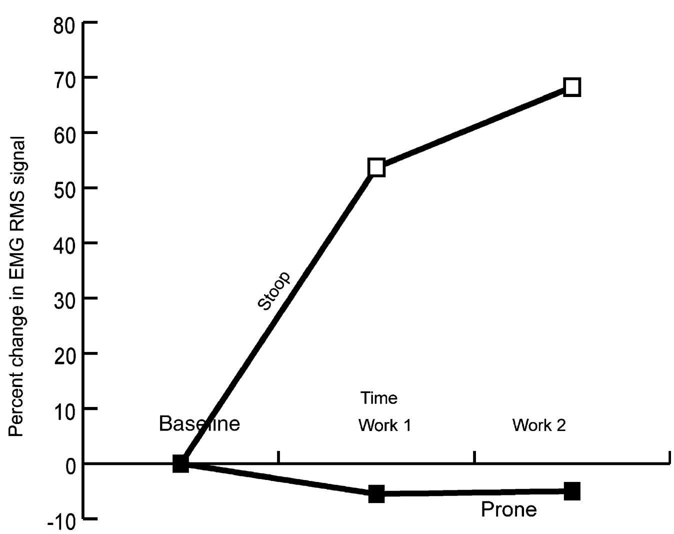

Fig. 4. Percent change in EMG RMS signal for Biceps femoris at baseline (left), after first work period (middle), and after second 15 min work period (right).

as this laboratory experiment since workers are given free choice of postures and are continually moving which allows greater blood flow to the hamstrings, versus the static contraction that was held during the experiment. Neck discomfort was similar in both postures, however, when looking at prone discomfort by itself, neck and upper back had the highest mean discomfort rating (2.27 and 2.07, respectively).

Matilla also compared EMG activity for erector spinae and trapezius and found reduced levels of activity in the compared to a standardized strain for a motorized prone cart. This study was the first to analyze the EMG signal for signs of localized muscle fatigue. The results of EMG RMS for the trapezius showed that the frequency and motions required in both postures contributed equally to localized muscle fatigue in the first work period. The hand and arm motions for both postures produced similar results, although the prone subjects work for a longer period. The break between work sessions could provide enough rest to allow for the subjects to recover sufficiently that no muscle groups indicated a continued trend in the fatigue signal. Another possible explanation for the lack of a consistent trend in the EMG values could be the recruitment of additional muscles in the shoulder girdle, back and upper leg to hold the weight at the last measurement, due to the fatigue caused by the first work period. The erector spinae muscle in the back indicate localized fatigue after the first 15 min work period for the stoop posture, and the back muscles maintain the same level of fatigue that developed during the first 15 min work session.

The studies by Rullman et al. (2003) and Matilla et al. (2002) used EMG activity to evaluate the prone workstations, based on the level of flexion in the spine, the activity levels may not indicate a high level of muscle contraction due to the force provided by the ligaments. The EMG RMS results for fatigue demonstrated that although the legs were not active during stoop posture, the erector spinae muscles were still fatiguing. The hamstring muscles, showing the highest level of muscular discomfort, maintained the same pattern of fatigue showing after the first

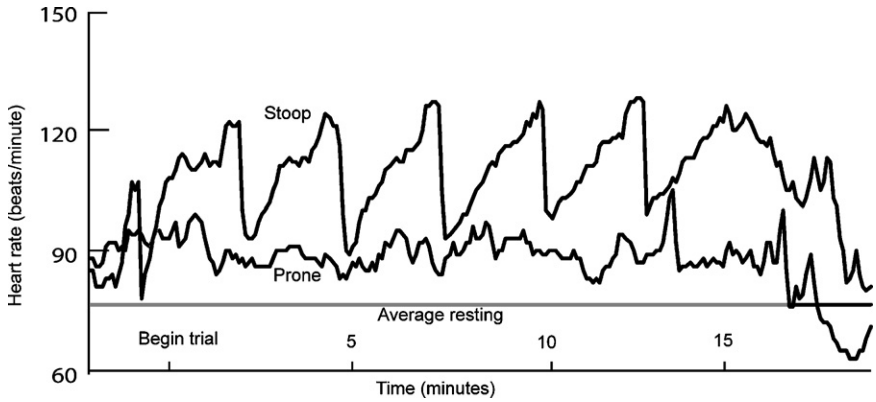

Fig. 5. Heart rate response to stoop posture (top), prone (center) and average resting (bottom).

15-min period for stoop posture. The current experiment asked the subjects to hold the stooped posture for 2 min intervals with only 30 s rest breaks which would indicate that there was not sufficient rest time for the muscle to fully recover.

The difference in heart rate is interesting since the stoop posture used in this laboratory study might underestimate the actual heart rate of a dynamically moving and changing subject in the field. Since the trapezius EMG showed similar results for both postures, we assume the work of the arms and hands contributes equally to heart rate for both postures. The difference between the two heart rates might indicate the amount of energy needed to maintain a static stoop labor posture. This lends support to the early work by Samann (1970), in which estimated energy expenditure and heart rates of different postures were compared to lying on the back. The percent change of heart rate in the current study are similar to the findings of estimated increase in heart rate in the prone posture by Samann (1970), who observed stoop heart rate was 17% more than lying on the back, while prone was estimated at 3% more than lying on the back.

Based on the current study, prone workstations have a significant advantage over stoop labor for short-term exposures. The results for discomfort, localized fatigue and heart rate provide evidence in favor of the prone posture, beyond the previously established increases in productivity. Future research is needed to determine the effect of working on a prone workstation during 4 and 8 h work length exposures on contact stress, discomfort, neck fatigue and upper extremity exposure. Additionally, the effect of creating a machine paced work environment compared to the current self-paced situation of piece rate labor should also be examined in future studies. One area of potential improvement based on the discomfort ratings would be improved head and neck support. In order to increase the adoption of prone workstations, additional study on the economic return for farms using piece rate laborers should be conducted. Investigations into reducing cultural and gender bias and worker reluctance should be considered to aid in their adoption. Future studies should also include field level comparisons with seasoned workers to determine if the results in the laboratory are similar to actual work conditions.

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