Modified PATH Methodology for Obtaining Interval-Scaled Postural Assessments of Farmworkers

E. B. Garrison, J. Dropkin, R. Russell, P. Jenkins

ABSTRACT. *Agricultural workers perform tasks that frequently require awkward and extreme postures that are associated with musculoskeletal disorders (MSDs). The PATH (Posture, Activity, Tools, Handling) system currently provides a sound methodology for quantifying workers' exposure to these awkward postures on an ordinal scale of measurement, which places restrictions on the choice of analytic methods. This study reports a modification of the PATH methodology that instead captures these postures as degrees of flexion, an interval-scaled measurement. Rather than making live observations in the field, as in PATH, the postural assessments were performed on photographs using ImageJ photo analysis software. Capturing the postures in photographs permitted more careful measurement of the degrees of flexion. The current PATH methodology requires that the observer in the field be trained in the use of PATH, whereas the single photographer used in this modification requires only sufficient training to maintain the proper camera angle. Ultimately, these interval-scale measurements could be combined with other quantitative measures, such as those produced by electromyograms (EMGs), to provide more sophisticated estimates of future risk for MSDs. Further, these data can provide a baseline from which the effects of interventions designed to reduce hazardous postures can be calculated with greater precision.*

Keywords. *Ergonomic assessment, Farmworkers, Interval-scaled data, Musculoskeletal disorders.*

The PATH (Posture, Activity, Tools, Handling) methodology was developed to better quantify ergonomic exposure in non-cyclic or non-repetitive occupations, such as construction or agriculture (Buchholz et al., 1996). This methodology involves live postural analysis of study participants in their usual work environment and produces data that classify joint flexion (or extension) as neutral, moderate, or severe. While the postural categories that are determined from real-time PATH observations are useful, their limitations are obvious. This can be seen when considering the cutoff values used for determining trunk flexion severity, which are neutral (<20°), moderate forward flexion (20° to 45°), and severe forward flexion (>45°) (Buchholz et al., 1996). In this scheme, for example, a sub-

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ject with trunk flexion of 21° is considered to be in an identical posture as a subject who is flexed at 44°. Further, a subject with 43° of trunk flexion is considered to be in an entirely different posture from a subject flexed at 46°. Neither of these results captures the fact that the first two subjects are in very different postures, whereas the second two subjects are in nearly identical postures. This is the shortcoming of using an ordinal scale of measurement to capture data that exist on an interval scale. In this study, a modified PATH methodology is used to provide a means of obtaining continuous, interval-scaled data that measure the actual degree of joint flexion. Further, any ordinal endpoints measured with the traditional PATH methodology, such as the postural categories mentioned above, are readily obtainable from the interval-scaled measurements of joint flexion captured here. It should be noted that variables that exist as true categories (such as sex) can, and have been, used in equations that estimate future risk of adverse outcomes. An equation that could be used to estimate the future risk of musculoskeletal disorders (MSDs) among agricultural workers, which are the most commonly cited non-fatal occupational injury or illness in this population (Brower et al., 2009; Earle-Richardson et al., 2003, 2008; Fathallah, 2010; McCurdy et al., 2003; Tonozzi and Layne, 2016; Xiao et al., 2013) would be particularly useful.

Given that postural stresses have been closely linked to MSDs in farmworkers (Davis and Kotowski, 2007; Fathallah, 2010; Kandel, 2008; Kirkhorn et al., 2010; Scribani et al., 2013; Xiao et al., 2013), covariates representing measures of postural stress would be key elements in an MSD risk prediction equation. Two continuous, interval-scaled covariates that could be included in an MSD risk prediction equation are measurements obtained by electromyograms (EMGs) and estimates from programs such as the 3D Static Strength Prediction Program (3D SSPP) (University of Michigan, 2017). EMG methodology is commonly used to measure muscular exertion in response to various postural loads, while 3D SSPP predicts static strength and force requirements for certain tasks. Methods for obtaining EMG measures in agricultural occupations have been described by Fathallah et al. (2016) and Jin et al. (2009).

The use of risk equations for MSDs can be found in the recent literature. Current examples include the revised NIOSH Lifting Equation (Ranavolo et al., 2017) and the Variable Lifting Index for Manual-Lifting Risk Assessment (Battevi et al., 2016). Further, recent applications of the Strain Index, originally proposed by Moore and Garg (1995), have been demonstrated by Kapellusch et al. (2017) and Garg et al. (2017).

Ideally, an MSD risk prediction equation would include interval-scale measurements of joint flexion. Because these measurements are difficult to obtain in the field with a constantly moving subject, many ergonomic analysis methods (such as PATH) measure subjects' posture on an ordinal scale, such as "neutral," "moderate," or "severe" flexion (Buchholz et al., 1996; Earle-Richardson et al., 2004; May et al., 2012). As noted by May et al. (2012), electrogoniometers worn by workers can provide continuous measurements of biomechanical movements and degrees of joint flexion. However, these devices are expensive and would likely limit worker participation due to their highly burdensome nature during field work. In this study, a modification of the PATH methodology allowed continuous measurement of joint flexion without the use of electrogoniometers. Rather than making live postural assessments of subjects as they worked, as in the original PATH methodology, photographs of the subjects were captured at regular intervals and then analyzed using photo analysis software. An additional benefit of this methodology is that, rather than requiring the presence of an observer who has completed a 30-hour training curriculum, only a photographer with minimal training is needed.

This article describes the methodology used to obtain measurements of joint flexion, in degrees, in a sample of ground crop farmworkers. The data produced are continuous, interval-scaled measurements of joint flexion in hand-weeding farmworkers. Such data could be combined with other continuous measurements, such as those produced by EMG and 3D SSPP, to develop an equation to predict future risk of MSDs in farmworkers. Further, this would provide a much more sensitive, quantitative measure of MSD risk reduction in response to an intervention.

This is the first report of such measurement in the occupational exposure literature, and it may provide a starting point for future workplace exposure studies in other occupational sectors.

Methods and Materials

Subjects

Forty-six migrant and seasonal farmworkers (MSFWs) employed on eight different farms involved in ground crop production were recruited to participate in the project. Farms eligible to participate had to employ at least four MSFWs and be actively growing and harvesting ground crops such as lettuce, onions, beets, carrots, and asparagus. Male and female subjects had to be at least 18 years of age and employed full-time on the farm.

Data Collection and Informed Consent Procedures

With the permission of the farm owner, two bilingual research assistants recruited eligible workers and obtained written informed consent at the work site. Ethical approval was obtained from the Bassett Healthcare Network Institutional Review Board in Cooperstown, New York.

In addition to snacks and beverages provided to subjects on the days that they were observed in the fields, a $25.00 gift card for a large retail chain was given to each participant at the end of the study. Subjects completed an interviewer-administered demographic survey in Spanish with a bilingual research assistant.

Work Posture Photo Protocol

Study participants were asked to wear large numbers on their sleeves that corresponded to their unique study identification. Research assistants also noted the subjects' clothing colors and other identifying features in case the identification numbers were obscured in any of the photographs. The study protocol called for a sequence of photos to be taken at 10-second intervals for ten consecutive minutes during which the subject had been assigned to hand-weeding. It was felt that the resulting 60 photos were adequate to capture the postures and positions of the subject for this single task (hand weeding). These 10-minute observation periods occurred equally in the morning and afternoon to ensure that the subjects were captured at all levels of fatigue throughout the day.

Field conditions, such as rain or mud, and cases in which the subject was reassigned to a task other than weeding (such as harvesting or packing produce) before the full ten minutes had elapsed caused some observation periods to be cut short. When this occurred, the research team attempted to complete the observations on a different day within the work week. However, it was not always possible to complete the 10-minute observation period for each subject due to the logistical difficulties of field crop work. Whenever possible, data were obtained for multiple workers from a single photograph when the subjects were working in groups. For these reasons, the number of photos and the total observation time per participant varied.

The photographer attempted to capture photos in the sagittal plane to ensure that the maximum number of joints would be visible. However, this was not always feasible because of the position changes and work practices unique to individual workers.

Image Processing and Analysis Software

ImageJ, a public-domain image processing and analysis program developed by the National Institutes of Health, was used to measure joint flexion in each photo. This software was used previously to perform quantitative postural analyses (Bini Rico et al., 2014; Linn, 2001; Omkar et al., 2007). In a review article of the predecessor of ImageJ (NIH Image), Linn (2001) described the various applications of the software in measuring static postures and postural changes. Validating the angular measurements made by ImageJ is difficult because of the lack of a "gold standard." Using precise angular measurements circumscribed on a rubber ball, Codarin et al. (2012) demonstrated that, even with very low camera resolution (3 megapixels), the estimates made using ImageJ had both very high intraclass correlation (ICC) and percent accuracy. Omkar et al. (2007) also used the methodology to satisfactorily measure small changes in angular measurements in response to therapeutic interventions.

In the current study, bony landmarks, with reference lines linking these landmarks, were used to obtain lower back, shoulder, and knee joint angles. The lower back angle was calculated using a vertical reference line, the L5/S1 spinous process, and the C7 spinous process. The shoulder joint was calculated using the superior portion of the iliac crest, the greater tubercle, and the midline of the shaft of the humerus. Knee flexion was determined using the greater trochanter, the midpoint of the knee joint, and the midline of the shaft of the tibia. Figure 1 presents an example of how reference lines and bony landmarks were marked by the photo analyzers to measure the three joint flexion angles with ImageJ.

Figure 1. Example of ImageJ measurements for the (1) trunk, (2) knee, and (3) shoulder joints on a digital image of a farmworker while hand-weeding.

Photo Analysis Protocol

The number of photos per subject ranged from 10 to 151. Ten photos of each subject were chosen at random for postural assessment, resulting in a total of 460 photos included in the analysis. Because the study did not have any *a priori* hypothesis to be tested, this sample size was based primarily on the logistics of available staff, rather than considerations of statistical power.

The degree of flexion of five joints was measured in each photo: the trunk, the right shoulder, the left shoulder, the right knee, and the left knee. While the postural assessments initially included the neck, both the ergonomist and the research assistant noted that measuring this joint was unreliable because of the angles at which the photos were taken, as well as the bulky clothing and hats that frequently obscured the joint. Therefore, the neck was not included in these analyses. Each measurement was rounded to the nearest degree.

Photo analysis and exposure assessment were carried out by an ergonomist and a research assistant. The research assistant was trained by the ergonomist in how to identify the three bony landmarks that were required to produce the angle for the ImageJ software. When the research assistant's training was completed, two sets of 55 practice photos were randomly selected and independently analyzed by the research assistant (Reviewer 1) and a certified professional ergonomist (Reviewer 2). The extent of agreement on the angle of flexion for the five joints was expressed as an average percent error calculated as:

$$\text{Margin of error (\%)} = [(\text{Reviewer 1} - \text{Reviewer 2}) / \text{Reviewer 2}] \times 100$$

Once an acceptable agreement (≤10% difference) was reached between the two observers, as explained below, the remaining photo assessments were performed by the research assistant.

Data Analysis of Study Photos

For the degree of flexion of the five joints, the mean and median values for each joint in each subject's ten photos were identified along with the interquartile range, minimum, and maximum.

Results

Subject Demographics

The sample included 23 men and 23 women. The average age was 33.3 (SD = 11.6, range 20 to 51) for females and 39.5 (SD = 10.0, range 20 to 62) for males. The dominant nationality was Mexican (N = 34, 76.1%).

Inter-Rater Reliability of Joint Measurements

For these continuous measurements of joint flexion, the margin of error (percent difference between the two reviewers' observations) was 17.7% for the trunk, 11.4% for the right shoulder, 20.2% for the left shoulder, 11.8% for the right knee, and 9.9% for the left knee. The reviewers discussed all results for which the joint angle measurements differed by more than 10° and identified the causes of the discrepancies. Following this discussion, a second round of measurements was made. These measurements are detailed in table 1. For the second round of measurements, the margin of error improved to ≤10% for all joints except the left shoulder (14.2%).

Table 1. Margin of error for two rounds of measurements of degree of flexion for various joints.

	Margin of Error (%)	
Joint	Round 1	Round 2
Trunk	17.7	5.2
Right shoulder	11.4	10.0
Left shoulder	20.2	14.2
Right knee	11.8	9.7
Left knee	9.9	9.9

Table 2. Summary of flexion in various joints based on ten photos for each of 46 farmworkers.

Joint	*N* (photos)[a]	Mean Degree of Flexion	IQR	Median Degree of Flexion	Range of Flexion
Trunk	298	69.6°	(59-87)	77°	0°-114°
Right shoulder	197	73.5°	(54-92)	77°	0°-129°
Left shoulder	213	60.2°	(44-77)	63°	0°-146°
Right knee	171	99.5°	61-147)	84°	24°-172°
Left knee	189	99.4°	(61-139)	97°	23°-175°

[a] Variability in number of photos due to obscured joints in photographs

Summary of Degrees of Flexion

A statistical summary of the angles of joint flexion is shown in table 2. As shown, both the mean (69.6°) and median (77°) degree of trunk flexion correspond to the traditional PATH criterion (>45°) of extreme forward flexion. The distribution appears to have some right skew, with the median exceeding the mean. It can also be inferred from the median values for left knee (97°) and right knee (84°) flexion that the subject was kneeling or crawling on the ground in most of the photographs. Flexion was greater for the right shoulder (median = 77°) than for the left shoulder (median = 63°), which is likely attributable to the right hand being most commonly dominant.

Discussion

Modification of PATH Ergonomic Assessment Methodology

In addition to the use of still photographs, the use of ImageJ software for joint flexion measurement is a significant modification to the original PATH methodology. This study is the first to use this software to capture more precise joint angle measurements. May et al. (2012) also modified PATH by taking videos of workers in the field, rather than performing live ergonomic analysis. The videos were converted to still photographs that were then printed so that joint flexion could be measured using manual universal goniometers. In this study, the use of photographs and ImageJ software allowed more time to assess the postures than is available when observing a constantly moving subject in the field. This added time should contribute to more precise joint angle measurement. Capturing photographs of workers also allows digital storage of the data (rather than prints), which can later be re-analyzed for certain work postures or joint angles of interest. These stored images can also be re-analyzed to make other PATH-related determinations, such as the relationship of posture to the task being performed or the tool being used.

Considerations for Data Collection

As with any continuous outcome, the definition of what constitutes an adequate number of observations (photos in this case) is based on the desired level of precision. Specifically, if the purpose of the study is such that relatively large margins of error, and resultant wide confidence intervals, are tolerable, then a relatively small sample size may be acceptable.

However, in cases where a higher degree of precision is required, a larger number of photo observations would be necessary. Therefore, each investigator must determine what constitutes an acceptable number of observations. A second key consideration is the time interval between photos. This determination must also be made by the investigator based on the task being observed. For tasks with relatively little variability over time, a shorter interval may be acceptable. In contrast, for tasks in which postures can vary widely throughout the day, photos may need to be taken over a longer interval.

Analytic Possibilities for the Data

Logistic regression, correlation, multiple linear regression, and analysis of variance are powerful analytical methods that can be used to quantify relationships between worker exposures, such as extreme postures, and MSD outcomes. While the use of ordinal-level data with these methods is problematic at best, interval-level data, such as the data captured here, are completely appropriate for use with these methods.

Although the data captured in this study could theoretically be combined with other interval-scaled covariates to produce estimates of future MSD risk in currently healthy workers, the feasibility of obtaining all of these measurements on the same workers must be considered. Unlike the data required for estimating cardiac risk, for example, which can be obtained from office visits and interviews, the data described here can only be obtained by careful study of workers in the field. Field studies with agricultural workers have been performed to explore the use of portable EMGs (Kirkhorn et al., 2010). However, even if this technology were readily available, the time and logistical complications required to obtain the measurements could cause an unacceptable interruption in the work day.

Another requirement for the development of a risk equation, whether for cardiac disease or MSDs, is the need for long-term (at least 10 to 15 years) follow-up of a cohort of healthy individuals. Given the current state of technology, this would be the most difficult aspect of developing such an equation, as farmworkers are a highly transient population (Hawkes et al., 2008; May, 2009). However, the rapid development of telecommunication technology (i.e., smart phones, etc.) may make long-term follow-up possible in the future.

In cross-sectional studies, postural stresses have been closely linked to MSDs among agricultural workers (Davis and Kotowski, 2007; Kandel, 2008; Ramahi and Fathallah, 2006; Scribani et al., 2013; Xiao et al., 2013). EMG readings would be essential in an equation to estimate the future risk of MSD in a currently healthy worker, as EMGs measure muscular exertion in response to various tasks and postures. However, to produce an accurate estimate of the future risk associated with these tasks or postures, continuous measurements of the worker's exposure, as captured by the data in this study, are key.

Study Limitations

A limitation of collecting data in the field during normal work days was that the angle at which the photos were taken could not be controlled for. The outcome of unfavorable camera angles in some photos was obscured joints and ultimately fewer data points. The photographer was also free to take photographs from whichever side of the subject (left or right) provided the greatest amount of postural information. Because this was typically the right side for a right-handed subject, the subject's bony landmarks on the left side were more difficult to locate. This may well have contributed to the relatively high margin of error (14.2%) for left shoulder observations.

Additional uncontrollable factors, such as workers being called away to another task, posed a challenge in obtaining the maximum number of data points for each subject. Further, although this method eliminates the need for the 30-hour PATH training session, there remains a time commitment to establish both adequate inter-rater reliability between the two photo analyzers and proper camera angling for the photographer in the field. It should be noted that while a high inter-rater reliability is encouraging, it does not guarantee the validity or accuracy of the measurements. Additionally, as a final study limitation, the extent to which this methodology could be applied to other agricultural work tasks or occupations is not known.

Conclusion

Reliable measurements of ergonomic exposure in this population on an interval scale (i.e., degrees of flexion) are possible. These interval-scaled data are superior to ordinal-level postural categories for any analytical method, such as correlation, logistic and linear regression, or analysis of variance. These methods are important tools when estimating the relationship of postural stress to MSDs in cross-sectional studies. Using these variables to predict future long-term MSD risk in an otherwise healthy population, while currently not feasible, is an intriguing possibility that may someday be realized, given the rapid advances in communication technology.

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