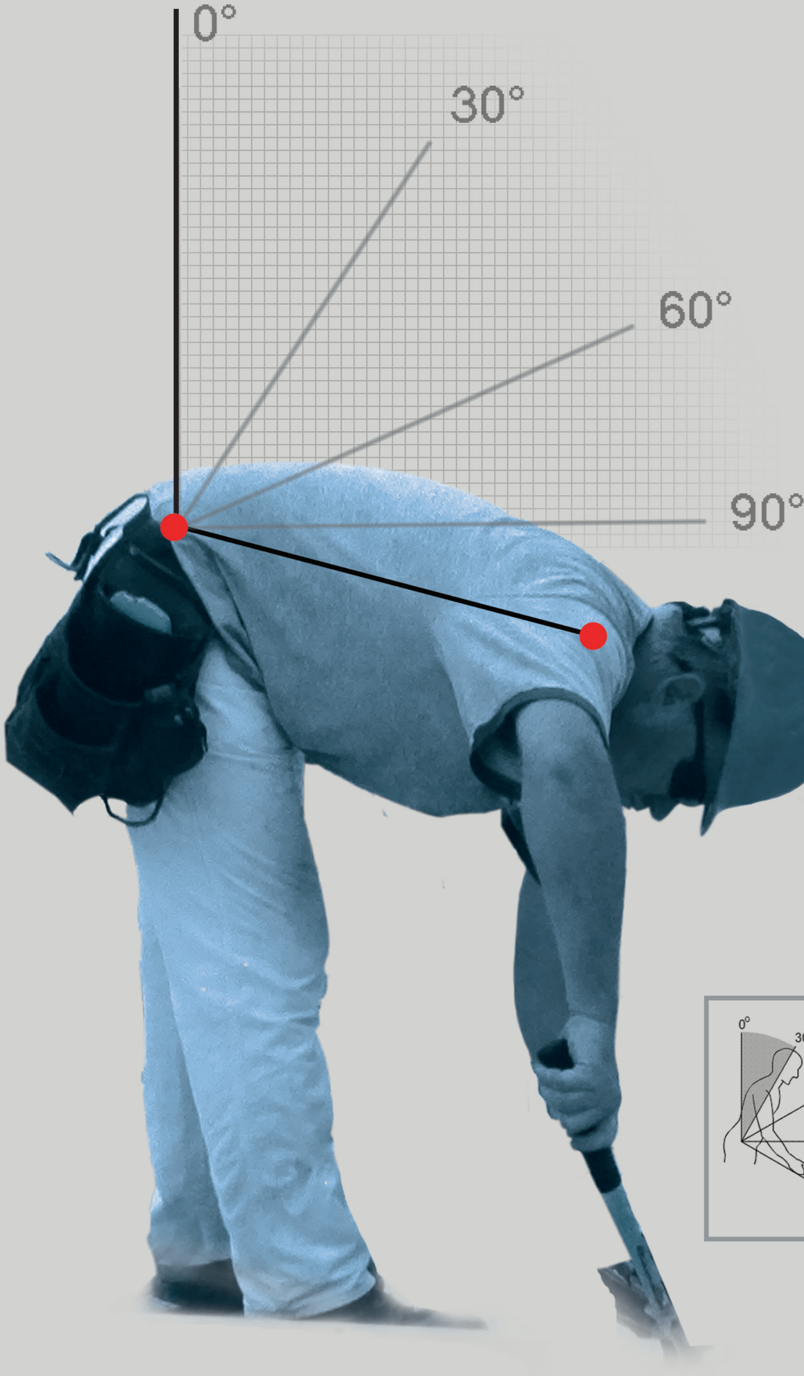
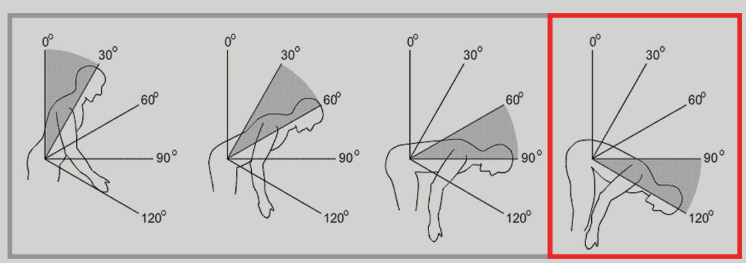
Observation-Based Posture Assessment

Review of Current Practice and Recommendations for Improvement





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Disclaimer

This guidance document is not a standard or regulation, and it creates no new legal obligations. It contains recommendations and descriptions of practices that have been shown to enhance observation-based assessment of working posture. The recommendations presented are advisory in nature, informational in content, and intended to assist occupational safety and health practitioners in providing a safe and healthful workplace.

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EXECUTIVE SUMMARY

This report describes an observational approach for assessing postural stress of the trunk and upper limbs that is intended to improve risk analysis for prevention of musculoskeletal disorders. The approach is supported by several recent research studies. These studies have evaluated how much time it takes observers to classify specific trunk and upper limb postures, how frequently observers are likely to make posture classification errors, and the magnitude of these errors. The frequency and magnitude of posture classification errors depend on how many categories (levels) are available from which to classify the specific posture. Recent studies suggest that optimal posture analysis performance is obtained by partitioning trunk flexion range of motion into 4 categories of 30° increments; trunk lateral bend into 3 categories of 15° increments; shoulder flexion into 5 categories of 30°; shoulder abduction into 5 categories of 30°; and elbow flexion into 4 categories of 30°. These categories are suggested because they optimize how rapidly and effectively analysts can visually judge posture. This report also presents more general guidelines for the video recording of posture and for the posture analysis process. Guidelines for video recording address such factors as camera position, field of view, lighting, and duration of recording. Guidelines for posture analysis address enhancements such as the benefits of digital video, computer software, training, and use of visual reference and perspective cues. Information in this report can assist health/safety, ergonomics, and risk management/loss control practitioners who conduct job/worksite assessments of lifting, pushing, pulling, carrying, and/or manual handling risk factors.

CONTENTS

GLOSSARY

Deferred posture analysis: Later analysis of body posture data collected (such as on video) in the workplace. This method lends itself to more detailed assessment because it allows many postures and events to be observed at the individual level.

Electrogoniometer: A device to quantify, in analog or digital form, an angle and changes of angles between body segments connected by a joint.

Mono-task work: An activity characterized by repeated stereotypical motions and exertions, without variation, usually associated with a repeating work cycle of short duration.

Parallax: A shift in the apparent relationship in position of an object when viewed along a different line of sight.

Posture analysis: Decision-making about the magnitude of a posture, relative to a convention specified in the tool or method used. For example, video can be used to record or collect body postures in the workplace. These postures can be analyzed later with software to determine the angle of the body segments, as viewed on the video.

Posture category: Any of multiple discrete intervals of angular position, usually defined by lines and/or arcs, into which a joint range of motion is partitioned.

Posture collection: The recording of postures in the workplace.

Real-time posture analysis: Observation, collection (via paper checklists or handheld devices), and analysis of body postures in the workplace while tasks are being performed (that is, in real time). Real-time posture analysis is likely to provide less detail because fewer events can be recorded simultaneously and the frequency with which dynamic events can be visually discriminated is lower.

Peak and cumulative posture assessment: Assessments of posture(s) associated with specific events within a task or job, typically to address the most severe posture adopted or the posture associated with the greatest load experienced by the worker. Cumulative assessments consider how the effect of posture and force accumulates over a specific period of work time. Note that cumulative assessments can be made of a single task or for all tasks that a job comprises, whether those tasks are the same (repetitive) or variable (nonrepetitive).

Variable work: Workplace tasks that are characterized by motions and exertions that are noncyclical and without a defined work cycle.

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BACKGROUND

The purpose of this document is to help practitioners assess working posture for the prevention and control of occupational musculoskeletal disorders (MSDs). Quantitative or semiquantitative descriptions of posture are inputs to many job analysis tools applied in MSD prevention and control. Studies of the relationship between risk factors (such as posture, repetition, and force) and resulting MSD prevalence have used various approaches to characterizing working posture, including observation-based methods. Posture classification by systematic observation of a worker is commonly used in research and by practitioners, such as ergonomists, industrial hygienists, and safety professionals, to help inform job design decisions and establish safe work limits to reduce MSD injury risk in the workplace.

Just as direct measurement methods have limitations in their ability to accurately assess exposure, it is equally important to consider the limitations of an observer in discriminating among posture categories (levels) that reflect increased exposure severity. Some estimation "error" is inherent in the use of any observation-based assessment tool. Recent studies have identified an approach to the selection of posture categories that reduces posture classification errors and improves efficiency, thereby providing an opportunity to improve posture assessment in the workplace. This report presents this recent evidence, which forms the basis for an emerging practice to optimize observation-based posture assessment performance and efficiency. A secondary purpose of the document is to help practitioners improve posture recording and analysis using observation-based assessment methods (See page 5).

Overexertion injuries to the musculoskeletal system (including those from lifting, pushing, pulling, holding, carrying, or throwing) cost U.S. businesses $12.75 billion (U.S.) in direct costs in 2009 and accounted for more than a quarter of the overall national burden [Liberty Mutual Research Institute for Safety 2011]. The situation is similar in Canada where a 2005 labor market report estimated direct and indirect cost of musculoskeletal disorders (MSDs) at $20 billion (CDN) [McGee et al. 2011]. In Canada, 26.4% of all injuries at work in 2003 were due to overexertion [Wilkins and Mackenzie 2007]. In Ontario, sprains and strains accounted for 50.2% of lost-time claims, and 46.6% of these claims were due to events such as overexertion, static postures, and repetitive motions [WSIB 2009]. In Manitoba, 60% of all lost time injuries are MSDs.

CURRENT PRACTICES IN JOB ANALYSIS FOR MSD PREVENTION

The goal of job analysis is to proactively identify factors associated with increased risk for work-related MSDs. In general, three approaches have been used to identify risk factors: 1) worker self-report, where the worker is asked to estimate the risk factor levels associated with his or her work; 2) observation-based methods, where a job analyst observes the work in real time or from recorded video, with a systematic approach to classifying risk factors; and 3) direct measurement, where instrumentation is used to measure posture directly. The relative advantages and disadvantage of these approaches can be considered in the manner shown in Figure 1 [Kilbom 1994; Winkel and Mathiassen 1994]. Observation-based approaches generally yield less valid assessments of risk factors than could be obtained by direct methods such as a motion capture system or electrogoniometer. However, observation-based methods can cost less, be more accessible, require less expertise, and be easier to implement for the practitioner in the field. It is recognized that the time and resulting cost associated with more detailed, video-based analysis (that is, deferred analysis) can be high, depending on the objectives of the analysis and the nature of the work.

A number of practical observation-based methods have been developed to evaluate musculoskeletal risk factors. In a recent review by Takala et al. [2010], 30 of the 32 observational approaches in the review assessed posture as a risk factor. Specific tools include, but are not limited to Rapid Upper Limb Assessment (RULA) [McAtamney and Corlett 1993], Rapid Entire Body Assessment (REBA) [Hignett

Figure 1. Comparison of worker self-report, observation-based, and direct methods for assessing musculoskeletal disorder risk factors, such as working posture. The green arrows (+) indicate desirable attributes, the red arrows (-) undesirable attributes (for example, high validity is desirable [+]; high cost is undesirable [-]).

and McAtamney 2000], Strain Index [Moore and Garg 1995], Occupational Repetitive Actions Index (OCRA) [Occhipinti 1998], TRAC [van der Beek et al. 1992] and other approaches reported in scientific publications [Armstrong et al 1982; Genaidy et al 1993; Seth et al 1999]. Posture is a key input in these analysis tools in which the analyst classifies a body segment position which is partitioned into posture categories. Each posture category represents a certain portion of the range of motion. (Table 1 shows the number of posture categories for the methods above.)

Although posture is recognized as a risk factor in all of these methods, it is often difficult to compare results among studies using the various methods. One reason for this is that postures have not been standardized across the methods in the size, and therefore number, of posture categories used to quantify working posture [Andrews et al. 2008a, 2008b; Keyserling 1986; Juul-Kristensen et al. 2001; Lowe 2004a; Weir et al. 2011]. One reason for the lack of consistency between studies is the nature of the job or task and that the characteristics of the physical exposures in the job affect the decision about type of assessment, sampling approach, and summary measures to be adopted. There are several types of assessments in which working posture is classified on the basis of visual observation, as shown in Appendix A. Though direct measurement technologies are improving, currently many practitioners are assessing physical job demands by way of observational judgment. The following section presents posture categories for observation-based posture classification that have been demonstrated to optimize observer performance and efficiency. These categories are defined for the spatial description of individual posture observations, in which a still image or isolated video frame of an event is defined. It is beyond the scope of this report to address statistical treatment of posture sampled over time. As the science, knowledge base, and measurement technologies relevant to posture assessment in MSD prevention and control are further developed, best practices will continue to evolve.

Table 1. Selected methods for MSD risk assessment and their associated number of posture categories. Each value represents the number of categories into which the posture range is partitioned.

	Trunk			Shoulder		Elbow	Forearm	Wrist	
Method*	Flexion	Lateral bend	Twist	Flexion/ extension	Abduction/ adduction	Flexion	Pronation/ supination	Flexion/ extension	Radial/ ulnar deviation
(1)	■	■	■	5	2	3	4	4	2
(2)	■	■	■	■	■	■	■	5	2
(3)	4	2	2	2	■	■	■	■	■
(4)	■	■	■	3	■	■	2	2	2
(5)	4	2	2	5	2	3	2	4	2
(6)	■	■	■	6	4†	4	3	5	3
(7)	4	2	2	4	2	3	2	5	2
(8)	4	■	■	4	4	2	3	5	5
Figure 2, present	4	3	■	5	5	4	■	■	■

*Method definitions and sources: (1) RULA—McAtamney and Corlett (1993); (2) Strain Index—Moore and Garg (1995); (3) TRAC—van der Beek et al. (1992); (4) OCRA—Occhipinti (1998); (5) REBA—Hignett and McAtamney (2000); (6) Armstrong et al. (1982); (7) Genaidy et al. (1993); (8) Seth et al. (1999).
†Horizontal abduction/adduction.

OPTIMIZING OBSERVATION-BASED POSTURE ASSESSMENT PERFORMANCE

The framework in Figure 2 has been shown to optimize assessment performance when consideration is given to posture classification error (how often errors are made and how large the errors are) and the speed of posture classification. Recent studies suggest that optimal posture analysis performance is obtained by partitioning trunk flexion range of motion into 4 categories of 30° increments; trunk lateral bend into 3 categories of 15° increments; shoulder flexion into 5 categories of 30°; shoulder abduction into 5 categories of 30°; and elbow flexion into 4 categories of 30°. (The research background for this framework is described in Appendix B.)

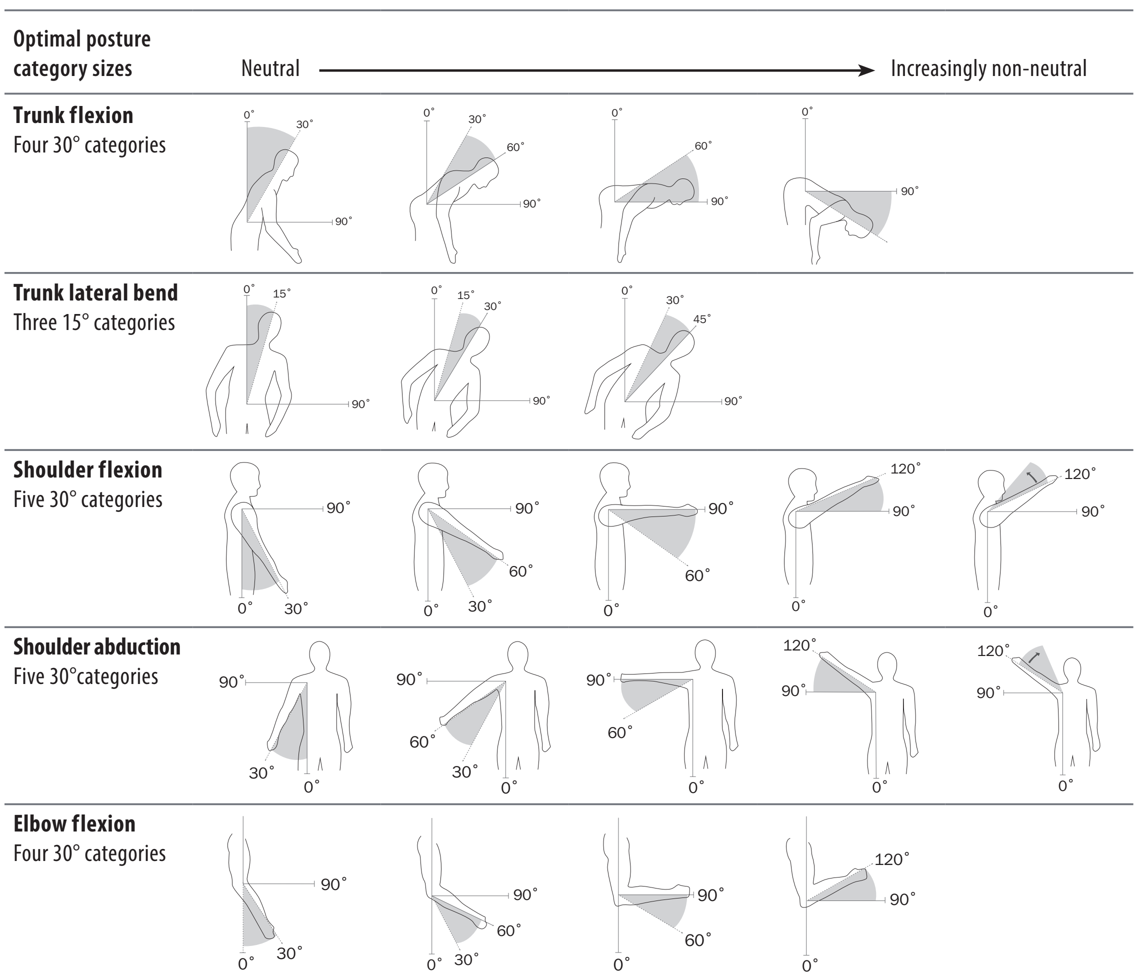


Figure 2. Posture category sizes suggested for trunk flexion, trunk lateral bend, shoulder flexion, shoulder abduction, and elbow flexion postures (illustrations from Andrews et al. [2012]).

ADDITIONAL RECOMMENDATIONS FOR OBSERVATION-BASED POSTURE RECORDING AND ANALYSIS

Video Recording

When working postures are video recorded for later analysis (deferred analysis), the quality and accuracy of the analysis will depend on video recording practices. The following are recommendations for video recording of work postures.

View	
Consider recording the task from multiple views.	The view of the worker is important and can impact the quality and accuracy of observations made using any method. Tasks that are performed similarly by both sides of the body (for example, right and left hands) and which occur mostly in one plane may only require a single camera view to capture an accurate sample of working postures. Asymmetrical tasks will likely require more views. For symmetrical tasks, views that are perpendicular to the main direction of movement provide valuable information. Some analysis methods allow for multiple views to be analyzed [Callaghan et al. 2003], which can be helpful when assessing highly asymmetrical tasks or tasks where a body segment is obscured by an object or by the worker's own body within a single view. Recording from several cameras at the same time in the workplace will provide multiple views, but the same effect can be accomplished, for repetitive tasks, by using one camera and recording several cycles from different vantage points.
Encourage the worker to avoid loose-fitting clothing.	In addition to physical barriers in the workplace, the clothing of the observed worker can interfere with observation-based posture assessments. Loose clothes or thick layers of clothing can be problematic for quantifying body postures. In many cases, clothing cannot be modified (for example, uniforms or personal protective equipment). However, if it is possible for workers to wear tighter or thinner clothes or garments that have less material (for example, short-sleeved vs. long-sleeved shirts and shorts vs. pants), it may improve viewing and analysis.

Lighting and Contrast	
Consider ways to improve lighting in the work environment or the camera's ability to deal with low light.	The amount of light and contrast between the worker and the work environment can affect real-time and deferred video-based posture observations, but it will likely have greater impact on video-based approaches. In general, good lighting and contrast are helpful and should be evaluated prior to video recording if possible, by taking a sample video and reviewing it prior to collecting all work tasks. If the worker moves between various environments during the assessment, then tests in each area might be needed if lighting and contrast are concerns. Portable lighting (mounted on a camera or tripod) can be used to improve viewing conditions. In advance of recording, determine the best positions and amounts of light needed for optimal viewing without interfering with the work being performed. A camera with good low-light capture capability may also improve the quality of the resulting low-light video.

Camera Movement, Stability, and Framing

Minimize unnecessary camera movement.	Observation-based posture assessment methods such as RULA [McAtamney and Corlett 1993] or 3DMatch [Callaghan et al. 2003] require observers to select posture categories that correspond to the actual body postures seen in real-time (RULA) or previously recorded video (RULA, 3DMatch). These approaches give the observer the freedom to move around the workplace so that an optimal view can be achieved at all times. However, posture analysis accuracy can be affected by how stable the camera view is. If the task requirements limit the range of motion of the work, a tripod could be used to ensure that the camera view remains consistent and smooth. If the worker has to move beyond the view of a stationary camera, the camera operator will need to move with the worker and try to keep the camera as stable as possible. Camera supports, monopods, or even a solid surface on which to rest the camera while it is strapped to the hand can help reduce camera shake, which can improve later viewing.
Zoom in on limb segments so that the joint of interest is as large as possible in the camera field of view.	It is also important to make sure that the body segments being assessed are in full view within the frame of the video. It may be difficult, because of obstructions and movement in the workplace, to get close to the worker without interfering. Use the zoom function to fill the frame as much as possible so that you are located at a safe distance and the view is not restricted. Because of the smaller size of the hand segment relative to the trunk and arm segments, a zoomed-in view of the hand is desirable when observation-based analyses of wrist posture are conducted. For more dynamic work activities, this may be difficult, because the hands may be moving in space and may move out of the field of view of a fixed-position camera. More posture classification errors can be expected when postures of the smaller limb segments and joints are estimated.
The best camera position is perpendicular to the plane of the joint(s) of interest.	Video images represent posture two-dimensionally, which challenges the observer if the camera view is not perpendicular to the plane of motion of interest at a specific joint. Perspective errors (parallax) can be introduced by the two-dimensional representation of posture in three-dimensional space and by a camera that is not ideally positioned with respect to the posture of interest. If the camera view is perpendicular to the plane of motion of the joint of interest, then a more accurate assessment of the angle can be made. When the camera view is not perpendicular to this plane of motion, perspective error may result. However, studies have shown that accurate posture classification can be attained in these situations [Sutherland et al. 2007] and that estimation error due to parallax is often less than would be predicted by the spatial relationship between the camera and the joint observed [Lau and Armstrong 2011]. Nonetheless, when possible, the camera should be oriented perpendicularly to the plane of motion to obtain an ideal view.
Consider acquiring video from multiple camera positions when an optimal view cannot be achieved.	If the ideal camera perspective cannot be achieved, then samples of the job can be obtained from multiple perspectives-either with two cameras simultaneously or with a single camera capturing different perspective views sequentially.

Duration of Observation	
Jobs with more variable postures may require longer observation periods.	The length of time for which postures should be observed depends on the type of task(s) the worker is performing and the nature of the analysis. If the analysis is for tasks that require the worker to do the same things repetitively, then observing only a few cycles or repetitions of the repetitive task is likely sufficient. Similarly, when evaluating the peak stress of a particular task, only a short period of time may need to be analyzed. Identifying the task associated with peak stress, particularly when this task occurs infrequently, often requires discussion with the worker(s). In cases where the work is nonrepetitive or when the cumulative effects of posture exposure are to be assessed, the work must be observed over a longer period of time. Generally, the more variable the work in terms of posture, the more observation time is needed to obtain a representative sample of the posture.
Conduct postural assessments of multiple workers, with particular emphasis on the workers exhibiting the most severe postures.	Workers vary in their body size (anthropometry) and work technique. These differences can result in posture and physical stresses that vary among workers performing similar (or identical) jobs. It is important to assess posture for multiple workers, preferably closer to the extremes in sizes, to ensure that the assessment of posture reflects that of the most severe cases.

Posture Analysis

The following are practical recommendations to improve analysis of posture from a video that has been recorded previously.

The definition of postures simplifies the representation of joint position for the purpose of characterizing postural stress.

Observation-based posture assessment can be enhanced by the definitions used for the postures themselves. For example, for the purpose of observational assessments, shoulder posture is typically simplified by considering a single "humeral-thoracic" joint – the angular position of the arm with respect to the trunk. This is a biomechanical simplification of the complexity of the shoulder girdle, which consists of multiple joints. Similarly, segment motions throughout the lumbar and thoracic spine are typically simplified in the definition of trunk postures to include trunk flexion/extension (or sometimes trunk inclination), trunk lateral bend, and trunk rotation. These biomechanical simplifications make it easier to visually estimate back posture for prediction of injury risk. They also require a compromise in the level of biomechanical detail that can be obtained.

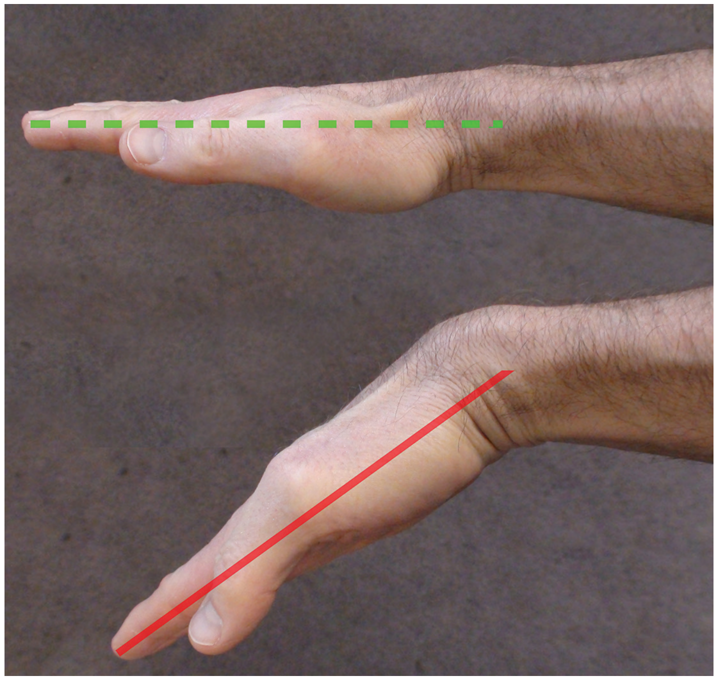
Visual reference of posture angles improves performance.

The observation of posture can be enhanced by providing the analyst with visual reference of the joint angles defining the posture categories. These are graphical representations of the posture category boundaries. The analyst's task is then one of matching the observed posture to the reference images rather than the more challenging task of directly estimating an angle between limb segments. Recent work has shown that adding a more salient border, either monochrome or colored, to the posture category diagrams decreases decision time for classifying the posture, in comparison with displaying the posture categories without borders [Andrews et al. 2012]. Error rates were also lower overall when line borders and shading were presented. Adding a border enhances the posture category salience, thereby improving the efficiency and accuracy of posture matching.

Visual cues can assist judgment of posture when camera view is not perpendicular to the joint motion.

When camera position limits an ideal viewing perspective, estimation of joint angles can be enhanced through the use of visual cues. An example would be the use of relative length of the hand and fingers to classify wrist posture [Lau and Armstrong 2011]. Wrist flexion/extension is not well observed from a dorsal (back side) view of the hand (Figure 3). This camera position makes judgment of wrist flexion/extension difficult because the flexion/extension motion plane is not perpendicular to the camera view. However, a change in the hand length with respect to hand width is a length cue indicating a flexed or extended wrist. The hand length is shorter (relative to hand width) in the right panel.

Ideal view



Non-ideal view

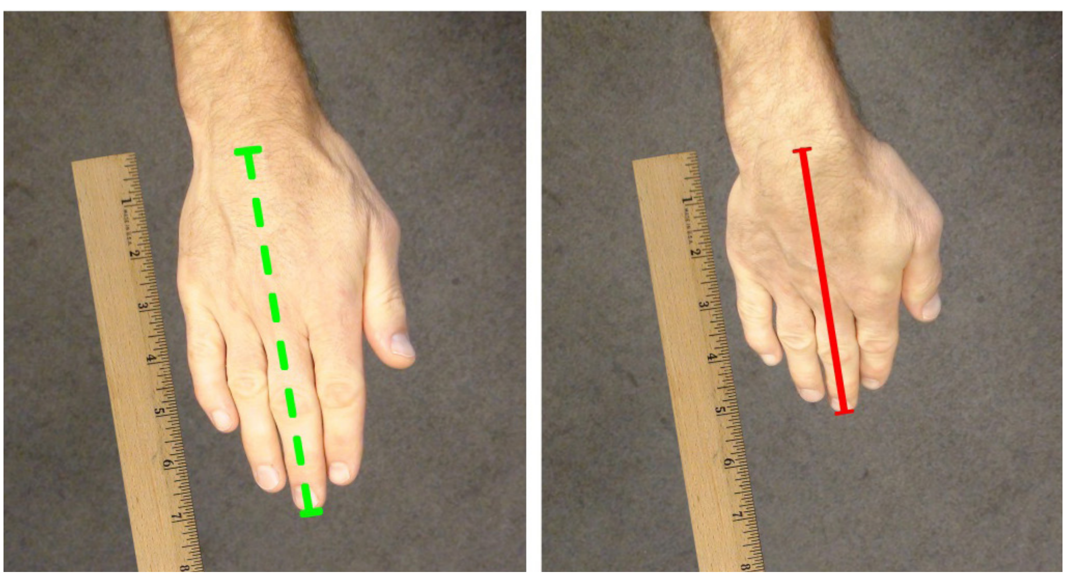


Figure 3. Ideal view for estimating wrist flexion (top image) is perpendicular to the joint flexion motion plane. In a non-ideal view (bottom images) the observer can use other cues, such as length perspective, to identify wrist flexion. The hand appears shorter in the flexed wrist posture, relative to neutral posture.

Consensus of multiple job analysts is more accurate than assessment of a single analyst.

Evidence suggests that a consensus group estimate by multiple observers, or an average of their estimates, improves posture assessment [Latko 1997]. When multiple observers estimate or rate posture severity, the average of these ratings is likely to be more accurate than most individual ratings. However, this approach is more time and resource intensive because of the need for multiple observers, and it will decrease the speed of the posture assessment method. It may be feasible in a research application, but it may be less practical in an industrial application.

Software programs and other computer-based approaches can assist posture analysis.

Video of working postures is being collected in digital format routinely, if not exclusively, in the workplace today. Computer software applications have been developed to enhance the manipulation of digital video for the purpose of posture analysis. For instance, computer software programs can be written to calculate two-dimensional angles directly from screen coordinates of mouse clicks on anatomical landmarks. If the video image plane is parallel to the plane of joint motion, then the software can accurately calculate the angle. However, as described previously, perspective errors will be introduced when the camera is not perpendicular to the plane of joint motion. Computer software programs have been developed for an analyst to mark exposure category transitions on a timeline synchronized with video playback. Changes in work posture can be denoted as exposure category transitions. These software programs perform summary calculations of cumulative exposure time for the manually identified posture transitions on the timeline [Yen and Radwin 1995]. Time study reports can then be generated, which show cumulative representations of posture, reflecting the duration of exposure to non-neutral postures and/or to inform analyses of cumulative load. These software tools enable detailed analyses of posture and summaries of results for video segments. However, these analyses can be time consuming, and some authors suggest that analysis time may be up to 30 times the real-time duration of the video segment [Heberger et al. 2012].

Training may improve posture classification performance.

Training and experience in ergonomics have been shown to affect both decision time and accuracy of posture classification. Training has been shown to improve the reliability of industrial inspection performance and to decrease the decision time of analysts coding postures [Weir et al. 2011]. In both cases, active involvement on the part of the inspector/analyst during training was critical to success. Inexperienced analysts appear to benefit more from training than experienced analysts [Weir et al. 2011], but there is error inherent in all perceptual tasks. However, regardless of experience, all analysts can make improvements in their performance with practice [Andrews et al. 2008b].

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APPENDIX A

Types of Job Analyses Based on Observational Assessment of Posture

Compliance with Ergonomic Guidelines (Ergonomic Audits)

Many organizations have established guidelines or limits for acceptable working postures to reduce physical stresses on their workers. Evaluating compliance with such guidelines involves observation of work processes and identifying postures exceeding an established limit. The observation involves screening a task for any postures exceeding the limit. Often a single posture threshold is referenced, or jointly observed risk factors may be referenced (for example, exertion of force in addition to posture exceeding a threshold).

Example

A company's ergonomics guideline includes the screening for unacceptable wrist posture in combination with force exerted by the hand. Unacceptable wrist posture is defined by 50° extension, 75° flexion, 15° ulnar deviation, or 10° radial deviation. The occurrence of any of these postures, combined with hand force exertion, triggers immediate action by way of job redesign. An ergonomics team member conducts an assessment of a new process, which involves observing work posture when a load is handled and identifying the presence of a bent wrist. This is done in a real-time analysis.

Another company's ergonomics program sets an exposure limit to the duration of time for working postures in which the trunk is flexed greater than 30°, simultaneously with a shoulder flexion posture exceeding 45°. This is done as a deferred analysis from a video recording of the work, so that the slow-motion and freeze-frame features of the video playback can be used to assess simultaneous postures.

Static Approximation of Biomechanical Loads

This involves calculation of biomechanical forces and moments on the musculoskeletal system for specific static working postures. It is typically performed when peak levels of biomechanical stress are of interest. Often, posture assessments are coupled with a measurement of external force (for example, load in hands, weight of lifted object). Use of a video recording allows identification of a specific exposure event, which can then be observed statically for estimates of posture.

Example

An ergonomist conducts a static biomechanical analysis of a worker lifting luggage from a conveyor to a screening area. Lifting posture is observed at the instant the load is lifted from the surface. Joint angles for the posture are estimated from a still image from a video recording of the task event, and these postural angles are entered in a biomechanical analysis software program to calculate estimates of forces and moments on the low back and to predict injury risk on the basis of the work posture and task conditions.

Assessment of Exposure to Risk Factors in Mono-task Work

This type of assessment is commonly performed in the analysis of repetitive, stereotypical motions and exertions where a unit of work is completed in a short period of time (often less than one minute). Assessments are typically based on continuous observation of several work cycles, which, because of their short duration, can be made in a few minutes. It is assumed that variation between work cycles is small and that posture exposure assessed for a short duration (a few work cycles) can be extrapolated over longer work durations, such as the full work day. Summary measures include the most frequently observed posture, the most extreme posture, and the amount of time the working posture was observed within specific posture categories.

Example

A repetitive assembly process is assessed before (in its current form) and after a workstation intervention is implemented to reduce reach distances to part bins. The Rapid Upper Limb Assessment (RULA) method [McAtamney and Corlett 1993] is used, and three employees are evaluated with both the conventional and modified design. The RULA method assesses the posture extremes of the upper limbs and the duration of time observed in the posture categories (most frequently observed posture).

Assessment of Cumulative Exposure to Risk Factors in Variable Work (Non-Mono-Task)

Variable work lacks a cyclic pattern (in the task elements, motions, or postures) that would allow results from short, continuous observation to be meaningfully extrapolated over a full work shift. Observation-based approaches are impractical for continuous monitoring over long periods. An accepted sampling approach to this variability is periodic observations to document posture at predetermined intervals to statistically infer the occurrence of exposure events. Such sampling approaches seek to determine the frequency of the exposure events (posture categories), such as the percentage of work time a joint is observed in a non-neutral posture or a cumulative exposure to postural stress. Time-sampling approaches can be complex and include whole- and partial-interval sampling, as well as fixed- and random-interval momentary-time sampling.

Example

A safety specialist is interested in assessing MSD risk factors associated with a trenching process. The work is observed in real time at fixed intervals, and gross postures are documented over the course of a 4-hour work period. The analyst observes a crew of workers performing the process during each sampling period. Observations are made at fixed intervals of 60 seconds, and the specific worker for each observation is selected at random from the crew, prior to the observation period [Buchholz et al. 1996].

A similar fixed-interval or momentary-time sampling strategy was used to evaluate the effect of a behavioral intervention that consisted of providing individual feedback on computer users' working posture [Sasson and Austin 2005]. Analysts recorded instances of four posture variables (wrist position, neck position, back/shoulder position, and feet position). Each of these was defined dichotomously as either "safe" or "at risk," depending upon whether or not the joint was determined to be aligned with the neutral reference position (the "safe" posture). The percentage of safe observations was reported as the outcome variable. Observations were conducted for each of the four posture variables every 16 seconds (four seconds per observation), so that 20 observations were collected in a five-minute session, twice daily for 52 days. The recorded estimates of safe posture over time allowed the researchers to evaluate the behavioral effects longitudinally.

APPENDIX B

The Research Background for an Optimal Observation-based Posture Assessment Approach

Observation-based posture assessments rely on the observer's visual discrimination among categories of posture severity to classify posture. The number of categories is determined by the joint range of motion and the size of the posture categories. Justifications for establishing posture category sizes in observation-based methods have been varied, ranging from the idea that non-neutral postures place a worker at risk [Keyserling 1986] to a rationale based on muscle force and fatigue [McAtamney and Corlett 1993]. Juul-Kristensen et al. [2001] reviewed existing posture assessment methods and concluded that a 45° posture category boundary was used frequently because a 45° angle was believed to be easily distinguishable. Other approaches have considered the likelihood of posture classification error when discriminating among multiple posture categories and the size of the joint range of motion in establishing the number of posture categories. Lowe [2004a, 2004b] assessed upper-limb posture classification accuracy when the range of motion was partitioned into three and six categories and showed that the likelihood of classification error increased with more categories. Other work (for example, the 3DMatch approach of Callaghan et al. [2003]) has accounted for the size of the range of motion when partitioning the range into posture categories for the trunk, elbow, and shoulder.

Given that a goal of posture assessment is to optimize both analysis reliability and efficiency (time required to conduct posture assessment), van Wyk et al. [2009] determined the ideal trade-off between the magnitude of classification error and the number of classification errors. An interface similar to that of 3DMatch [Callaghan et al. 2003] was used, which showed graphical representations of standardized posture categories in various views. The analyst decided which posture category most closely resembled (matched) the observed posture in the video frame depicted on the screen (Figure B1) and then selected that category by clicking

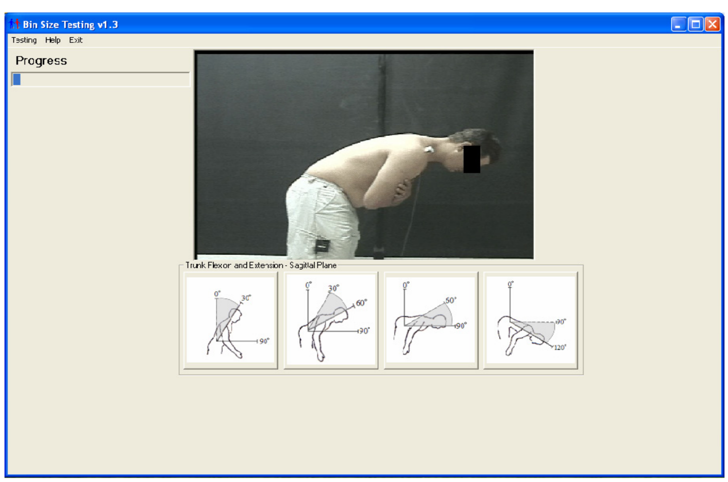

Figure B1. Sample interface used for determining the optimal posture category size (adapted from van Wyk et al. [2009]). Posture categories of different size were presented below video images with segments at known angles.

on it with a mouse. The same video images were randomly shown to participants on the interface above five different sizes of posture categories, ranging from a 10° category size (more categories in the classification) up to a 75° category size (fewer categories in the classification). The number of posture classification errors, the magnitude of error, and the decision time taken to make each posture selection were recorded. The number of errors represented a simple count of how many errors were made. The magnitude of the error was the number of degrees difference between the middle of the measured (true) posture category and the middle of the category selected by the observer.

Two curves were plotted as a function of the size of the posture categories in the scale. One curve represented the magnitude of the errors and the other the number of errors. The point of intersection of the two curves was identified (Figure B2) for postures of the trunk (flexion/extension and lateral bend), shoulder (flexion/extension and abduction/adduction), and elbow (flexion/extension). Selecting a posture category size larger than the intersection point resulted in fewer posture classification errors but a higher magnitude of classification error. Conversely, selecting a posture category smaller than the intersection point reduced the magnitude of error but significantly increased the number of posture misclassifications. An example of this is seen in Figure B2, in which the optimal posture category size for shoulder abduction was determined to be 30°. This information was used to establish the optimal posture category sizes shown in Figure 2.

The proximity of a postural joint angle in relation to the posture category boundary also has a significant impact on the analyst's ability to discriminate between adjacent posture categories. When an observed posture is closer to (that is, within 2°–4° of) a boundary between categories, decision time is increased by 7% and the posture is more likely to be classified incorrectly than when the posture is in the middle of the posture category [Andrews et al. 2008a, 2008b; Weir et al. 2011]. Implicit in this type of posture classification system is a trade-off

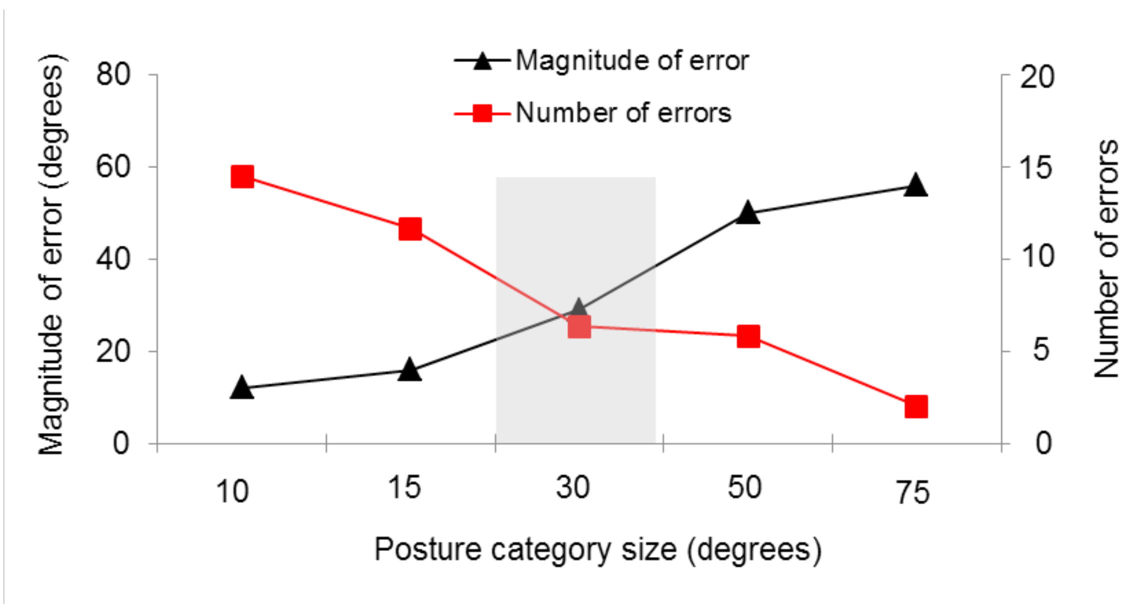

Figure B2. An example of the trade-off between magnitude of posture classification error and number of errors. The results depicted here are for shoulder abduction [van Wyk et al. 2009].

between decision-making time and accuracy of classification. In order to improve the probability of correct posture classification and reduce decision-making time, the posture categories need to be relatively large, with few boundaries. However, increasing the size of the posture category reduces the resolution with which a posture can be identified. This would impact the output of any biomechanical model that is used to predict joint or segment loads on the basis of the specific posture input [Andrews et al. 2008a].

Wrist postures of concern as risk factors for musculoskeletal disorders (MSDs) are non-neutral flexion/extension and radial/ulnar deviation. Posture of the forearm in pronation/supination (twist of the forearm about the long bones) is also observed in many job assessment methods. Optimal posture category sizes for the wrist and forearm have not been determined in the same experimental manner as those in Figure 2 for the trunk, shoulder, and elbow. However, it is reasonable to believe that the selection of posture categories for the wrist and forearm can be guided by the same trade-off between the number of errors and the size of a resulting error in the posture classification. An important consideration is the smaller size of the hand and forearm, which are observed in estimating wrist joint posture, and the narrower range of motion of this joint. The range of motion of the wrist from full flexion to full extension is approximately 150°. However, in radial/ulnar deviation, the range of motion of the wrist is much smaller, with ulnar deviation accounting for only about 30° of available motion (radial deviation is approximately 20°). A larger number of posture classification errors should be expected if one attempts to classify wrist postures with a precision that is equal (in number of posture categories) to classifications of larger joints such as the elbow or shoulder [Lowe 2004b]. Visually discriminating among multiple levels of wrist radial/ulnar deviation categories is likely to result in even more errors than with larger joints because of the difficulty of the task.

Assessments of MSD risk factors, including the assessment of posture, should have high internal and external validity [Kilbom 1994]. Internal validity refers to the degree of agreement between the observation-based measures of risk factors and reference standards for these risk factors. The studies described above have more firmly established expectations for internal validity, and it is largely this work on which the present emerging practice is based. External validity refers to how strongly the analysis method results predict risk of MSDs. Knowledge of the relationship between physical risk factors (including working posture) and MSD risk continues to be advanced through epidemiological studies of workplace injury prevalence and mechanistic studies of tissue response to physical loads. A complete review of evidence related to the relationship between physical risk factors and MSDs is beyond the scope of this document (for complete reviews see NIOSH [1997] and NRC/IOM [2001]). The approach described in Section 3 of this document is consistent with existing evidence related to the external validity of MSD risk prediction. For example, more generally, it is known that trunk posture affects biomechanical forces and moments about the lumbar spine and the activation of muscle tissue required to support and stabilize the spine in response to these external loads. Increasing exposure to flexion, lateral bend, and axial rotation of the spine increases risk for back injury. It is accepted that shoulder postures in which the arm is elevated create the potential for impingement in the subacromial and thoracic outlet spaces [Flatow et al. 1994] and place stresses on musculo-tendinous and joint capsule and ligament structures. Increasing arm elevation increases risk for impingement-related and rotator cuff injury.

More specific posture categories that validly predict MSD risk across diverse work situations, and in combination with other risk factors, are difficult to establish. For example, there is some evidence that MSD outcomes may be more sensitive to non-neutral posture than could be detected in the present approach to categorizing posture. For example, an epidemiological study by Punnett et al. [1991] adopted an a *priori* neutral category of 0° to 20° trunk flexion and showed increased injury risk with trunk postures exceeding 20°. This was demonstrated by calculating an odds ratio for the likelihood of injury when trunk flexion posture is less than 20° versus greater than 20°. The method presented in this document categorizes 0° to 30° as the neutral trunk flexion category, not because trunk postures less than 30° are necessarily of no risk but, rather, because trunk flexion posture is more reliably classified by observation with the 30° range. An observation-based posture assessment method must consider both internal and external validity of the posture classification (measurement).

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