An evaluation of the validity and reliability of an ergonomic risk factor checklist.

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An Evaluation of the Validity and Reliability of an Ergonomic Risk Factor Checklist

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ABSTRACT

Musculoskeletal injuries are being experienced and recorded in manufacturing facilities at an alarming rate throughout North America. These injuries are often being linked to repetitive motions required by the operations performed at the workplace. Hence the need has arisen throughout many manufacturing companies to find and utilize an objective preliminary assessment tool aimed at identifying the risk related to the repetitive motions. Since the mid 1980's, many ergonomic, health and safety consulting organizations, or practitioners, within manufacturing companies have developed their own methodology to analyze the ergonomic risk related to repetitive manufacturing operations. A simple screening tool validated by ergonomic research, and established criteria from the field, provides the practitioner and customers with an efficient and easy to understand method of analysis. The checklist methodology is aimed at comparing the exposure of these risk factors to known human capabilities established from the research criteria and guidelines obtained for each line item in the ErgoMAP. The ErgoMAP checklist, or some very similar iteration of it, has been utilized for over 6000 manufacturing operations at 15 facilities with one of the largest automotive manufacturing companies in the world. Thus, the purpose of this study was to utilize ErgoMAP checklist, that has been partially validated through an extensive review of literature, to further determine its validity and reliability. The initial validity of the line items was established through an extensive comparison to the appropriate research, as explained in the review of literature. Validity was further evaluated based on an epidemiological comparison between ergonomic injury statistics and risk factor values from the ErgoMAP checklist completed on actual automotive manufacturing
operations. Forty operations were studied and the total ErgoMAP score completed by an expert checklist user was compared to three years of incidence, lost time rate and restricted work rate injury data. Reliability was evaluated for both within-user and between-user. In a truck assembly plant, six checklist users were asked to complete an ErgoMAP checklist on the same six operations, four times, within an eight week period. The initial trial results were utilized across subjects for the between-user study. The total checklist score was utilized to analyze the coefficient of variation both, between and within-users. Also a count was taken from each user on every line item, to determine the consensus of identifying ergonomic risk. From this study, the major automotive manufacturer in question will have the data necessary to complete a blanket ErgoMAP study throughout the entire company. The results of the three portions of the study lead us to believe that the tool will be able to highlight and prioritize the potential risk of ergonomic injury throughout each assembly facility.
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LIST OF NOMENCLATURE

ErgoMAP: The title of the preliminary ergonomic checklist / screen tool
RV: Repetition Value
LWD: Lost work day
RWD: Restricted work day
OSHA: Occupation Safety and Health Association
CV: Coefficient of Variation
Chapter I: INTRODUCTION

The ergonomic risk factor checklist referred to in this thesis was initiated in 1997 as a mere screening tool used to justify the need for further ergonomic analysis and has become a popular tool for both proactive and reactive injury reduction initiatives. The "ErgoMAP" checklist has been used by a wide variety of groups and people over the last four years within a major automotive manufacturing company. This checklist has replaced a screening tool that previously required the user to provide a "yes" or "no" answer to approximately fifteen subjective statements or questions (See Appendix A), thereby giving a very vague understanding of the ergonomic implications related to the operation being observed. However, with the creation of the new "Ergo-MAP" checklist the entire risk factor identification process has received increased attention and credibility corporate wide, due to the utilization of actual design criteria taken from published ergonomic research.

The ergonomic risk factor checklist (ErgoMAP) refers to the Ergonomic Manufacturing Assessment Protocol that has been designed to provide users with the opportunity to develop a better understanding of the ergonomic implications associated with the particular workstation and worker assignment being surveyed. The ergonomic risk factors that are considered in this survey will be a combination of force, posture, repetition and other environmental related issues.

The checklist was designed to ultimately reduce the level of ergonomic risk that operators are exposed to, that may one day lead to work related cumulative trauma disorders. This can be achieved through identification and elimination of the ergonomic factors that have been deemed risky, through epidemiological, biomechanical or
psychophysical research. This risk factor checklist was designed to aid an automotive manufacturing company in the successful completion of its goals, related to lean manufacturing and injury reduction. The checklist is a simple and fast method of identifying potential ergonomic problems related to assembly operations. The checklist has an accompanying manual that was developed to help train potential users that may include Joint Health and Safety Committee members, methods engineers, union representatives, supervisors and operators. The manual and training sessions are essential ingredients to ensure proper use of the checklist. The checklist is a quantitative analysis tool aimed at detecting any red flags or triggers that may lead to ergonomically related disorders if left unnoticed and unresolved. When filled out correctly, this checklist is intended to assist an Ergonomist in an in-depth study of all the physical requirements involved in the job. It is predicted that the ErgoMAP checklist will help speed up the in-depth ergonomic assessment process for an Ergonomist, by having the major risk factors highlighted and identified prior to beginning the analysis. Please refer to Appendix B for a copy of the ErgoMAP checklist in its entirety.

So far, the usage of this tool has provided manufacturing plants with risk factor scores that allow any trained user to make educated decisions on the ergonomic implications of certain operations. The checklist was originally utilized by industrial engineers and health and safety representatives at multiple automotive assembly plants for all reactive ergonomic concerns. Recently, the ergonomic design organization within this company has adopted the checklist as their official, preliminary design tool and is enforcing a process that ensures the utilization of the ErgoMAP checklist on every new
assembly operation entering a facility. Important and sometimes costly decisions are being made based on the final score attained from the analysis.

To date, the ErgoMAP checklist, or an early version of the same tool, has been completed on over 6000 automotive assembly operations within the company at a minimum of nine different locations. Also, the checklist has been used on over 1000 other manufacturing operations at a minimum of six power train, stamping and component facilities within the company. The checklist has already been used as a before and after tool for quantifying the degree of ergonomic risk improvement or degradation during the launch of new or revised assembly process. The screening tool also provides a predictor for the return on investment of ergonomic related projects, by utilizing a numeric value to compare and prioritise risk between numerous assembly operations.

The original ErgoMAP checklist that was developed in 1997 (See Appendix C) was used to analyse approximately 1500 operations at one automotive assembly facility in Windsor, Ontario, Canada. The utilization of the checklist for these 1500 operations at one time, created the opportunity for the ergonomic staff to compare and rank the risk factor scores of every operation in the facility. This blanket study that took place in 1998 and was also completed to determine which line items generate risk factors when utilized throughout an automotive assembly facility (See Appendix D). The results from this study indicated how many operations had a risk factor line item with a given score greater than zero. Observing the number of times each risk factor line item was highlighted throughout the plant was an excellent tool to determine the need and applicability of each line item. This information has helped revise and redefine some of the line items over the past three years based on actual checklist line item practicality.
The results of the occurrence study were used to eliminate certain line items based on objective data from the manufacturing shop floor that showed low to no action on certain line items. The results from this study were utilized to help develop the most recent version of the ErgoMAP checklist that will be utilized for this thesis study.

Many tools and methods for measuring force and postural risk level including photography, goniometers, electromyography and accelerometers are available but have been considered to be impractical for large plant wide evaluations of every operation, due to the cost, complexity and potential invasiveness of the technique. Results from other, more non-invasive methods including visual observation and manual recording with surveys such as the BREIF (Humantech, 1994) or RULA (McAtamney and Corlett, 1993), have been considered to be vague and overly conservative by the ergonomic staff at the manufacturing company referred to in this proposal. The creation of false positive results from overly conservative tools can prove to be very costly for such a large company. Therefore it is extremely important that the line items and risk factor criterion used in the ErgoMAP checklist be heavily rooted in the literature and partially validated by previous epidemiological and clinical ergonomic research.

Validation from the literature is not the only measure of how accurate the results of this tool can be. In fact, checklist reliability has been a focus in the past for other researchers. Another one page checklist for evaluating ergonomic risk factors had a study completed on it to determine the reliability of the tool, as part of a joint UAW / GM ergonomics intervention program (Keyserling, et al. 1992). That study had the checklist completed by subjects (assembly workers) with limited ergonomic training, on 335 jobs in four manufacturing plants. To assess the reliability of the checklists provided by the
subjects, an intra-subject comparison of 51 operations was completed. The comparison involved the results of the subject checklist and the results of an "expert" computer aided video analysis performed by university personnel with extensive ergonomic job analysis experience. A lack of agreement between the subject checklist and expert results was found and attributed to a lack of subject training in ergonomics (Keyserling, et al. 1992). The analysis of reliability for the ErgoMAP checklist to be described in this thesis will involve only experienced manufacturing engineers or safety personnel who have specific training on the checklist itself. Another explanation for the lack of consistency between the subject and "expert" checklist results in the Keyserling et al (1992) study was that the subjects looked directly at the job on the shop floor, while the expert analyses were completed using video tapes. The ErgoMAP reliability study had all checklist analysis performed on site with the same completion time period for each subject. Also, due to lack of resources, the Keyserling et al (1992) study between the UAW / GM did not review the effects of different analysts studying the same job. Whereas this thesis study did encompass a between subject or intra-subject reliability evaluation. Even though the Keyserling et al (1992) article proclaims, "the one page checklist was found to be an effective instrument for identifying potentially harmful exposures" more research is required for within user, between user reliability and epidemiological data to determine true checklist effectiveness.
1.1 Statement of Purpose

The purpose of this thesis is to determine the validity and reliability of an ergonomic risk factor checklist that has already been compared to, and partially validated by, clinical and epidemiological research in the field. This research validation is explained in the review of literature for each line item within the checklist. The ErgoMAP checklist is going to be utilized by at least one major automotive manufacturing company as "the tool" for identifying ergonomic risk related to the repetition rate, force and posture required for every operation available. The primary users of this checklist are currently part of the ergonomics design staff, each with extensive backgrounds in Occupational Biomechanics, Industrial Engineering and Kinesiology. However, the utilization of the checklist must spread to other users outside of this corporate ergonomics group in order to sustain the process for all refurbished tooling, equipment or redesigned operations within the plants. Thus, establishing the validity and reliability of the tool is crucial to both the credibility of its results and the success of the decisions and corrective actions determined by the checklist scores.

1.2 Statement of Hypotheses

1) It was hypothesized that different users of the ErgoMAP checklist will reliably identify ergonomic risk, when completing the analysis on the same operations.

2) It was hypothesized that any user of the ErgoMAP checklist will reliably identify ergonomic risk on the same operations over a course of four separate analysis trials.

3) It was hypothesized that the ErgoMAP checklist scores will be positively correlated to the historical epidemiological statistics recorded across forty manufacturing operations.
1.3 ErgoMAP Checklist Overview

The checklist title, “ErgoMAP” is short form for Ergonomic Manufacturing Assessment Protocol. The checklist name has evolved due to the increased utilization of the screening tool. A tool that was once utilized for only one job at a time is now used as a protocol for assessing ergonomic risk on thousands of manufacturing operations throughout many different facilities within a major automotive manufacturing company.

1.3.1 Operation Description

The header of the checklist contains very important descriptor fields, for information that can be used to link the checklist to the actual location of the operation studied and the written manufacturing standard work instruction (SWI) related to the job. The checklist user is expected to fill out the following information related to the manufacturing operation.

- **Facility Location** – Each plant or manufacturing facility has a name and location that describes it.
- **Division** – Each operation resides in a division or department. For assembly facilities, those departments are body and white, paint, assembly and material handling. Power train, Stamping and Component manufacturing facilities have other division names and breakdown schemes.
- **Job Name** – Each operation has a name that describes, the primary task related to the job.
- **Zone/Area** – Within each department are zone numbers or areas that describe a specific manufacturing line or group of operations.
- **Column Location** – The column location is part of a grid map in each facility that positively identifies where the operation resides within the facility.
- **Station Number** – Each operation has a station number that will be identified.
• **Actual Cycle Time** – Every facility has their own published cycle times that will allow the user to determine which “repetition value” category they should use.

• **Supervisor or Facilitator** – This field refers to the name of the management person responsible for the job on the day that the operation is reviewed. This field also helps identify which shift was studied.

Once the operation description information is filled out in the header portion of the ErgoMAP form, the user must then utilize the checklist to identify ergonomic risk related to the operations being witnessed.

### 1.3.2 Element Description

The company referred to for the use of the checklist has an assigned written work instruction, which outlines the actual elemental responsibilities required for the successful completion of each manufacturing operation. The “element” column, allows the user to pinpoint exactly what part of the operation is causing the risk factor to occur at the assigned repetition rate. Some of the facilities have element numbers that are built into their work instructions, while others merely have a short work description to identify the specific task. When ErgoMAP checklists are completed on operations as work instructions change from year to year, this piece of information is extremely important to help track the element causing the risk. It is intended that the checklist user may then be able to predict the effect a certain element may have if moved to other workstations.

### 1.3.3 Comment Section

The checklist user is encouraged to describe the details of the task that is causing the risk. The comment section allows a checklist user to explain the exact work related motion that is causing the risk factor. For example if the risk factor line item highlighted is “reaching greater than 20” from the body” and element description on the work instruction merely says pick up part, the future checklist reader has no idea that the part
must be picked up from the back of a container at full arm’s reach. The comment section allows for this type of explanation.

1.3.4 Risk Factor Rating and Identification

This working form or document is merely a trigger point survey, to identify motions or exertions that may be deemed as an ergonomic risk based on research in the literature, when combined with repetition. The force related action limits and joint rotation limits were derived from both clinical and epidemiological research. The actual basis for the guideline, including the population that it was set to accommodate, is presented in the Review of Literature for each ErgoMAP line item. Research into the work factors related to repetitive motion injuries, has identified repetition, force and posture as the three most influential risk factors.

1.3.4.1 Frequency or Repetition Rate

This category is the underlying factor behind all cumulative trauma disorders. Without continuous repetition over the course of the shift, the risk level of the postural and force limit criterion values provided in the checklist would be greatly reduced. This means that the allowable force and posture risk factor limits would be much higher if the frequency or repetition rate was minimal. Therefore, it is important to match each risk factor identified from the checklist with a corresponding repetition rate, based on the overall cycle time of the operation. The overall cycle times are broken into the following three categories:

A. Cycle Time > 1 min  
B. Cycle Time > 30 sec. ≤ 1 min  
C. Cycle Time ≤ 30 sec
The category "B Cycle Time > 30 sec and ≤ 1 min" was intended to be the nominal category, due to the fact that the force and posture guidelines obtained from the research, were related to that specific repetition range. Therefore, the risk factor scoring system for categories A and C were increased and reduced in relation to category B. Once the cycle time is established, the scoring scheme explained in detail on the form itself will be utilized to determine the repetition value for each risk factor witnessed. Decisions for repetition values will be further clarified in the Review of Literature section on repetition.

1.3.4.2 Force

Movements or exertions that required excessive force are usually found in some form of manual materials handling or equipment maneuvering. These exertions are analyzed by ergonomic practitioners using formulas and equations to determine action limits for each of the possible parameters found in the task. However, the first section of the checklist was designed to identify forceful exertions and compare them with values that are easy to identify. When an operator is found to be performing one of the forceful exertions at a level that is greater than the guideline posted in the specific line item, the checklist user will determine the repetition rate utilized to perform the task and identify the specific risk factor score listed for the appropriate cycle time.

1.3.4.3 Posture

The human body is designed to operate through a very wide range of motions. Awkward posture, for the purpose of this checklist refers to large deviations of joint angles, away from the neutral or anatomical position. These postures can occur in the workplace when operators are either forced by the design of the human / machine interface, or choose to work outside of their normal range. This checklist is aimed at
identifying, and ultimately eliminating, the awkward work postures caused by the design of the workstation itself. However, the tool can also be very instrumental in highlighting and changing poor postures caused by operator method.

1.3.4.4 Other Risk Factors

This category is based on some of the more general and or environmentally related ergonomic risk factors that are prevalent in the literature. These line items have either a clinical or epidemiological relationship to cumulative trauma injuries. Some examples include vibration, energy expenditure and direct contact stress or pressure.

1.3.5 Sample Assessment Priority Legend

An informal epidemiological evaluation of close to fifty operations was also completed at one automotive assembly facility in Windsor, Ontario, Canada in 1998, to determine low, medium and high risk factor totals as compared to injury statistics within the facility. The information from that research, combined with a comparison of all of the risk factor scores throughout the facility, led to the determination of risk factor levels, based on the total cumulative value. Thus, the red, yellow and green scores indicated at the bottom of the ErgoMAP checklist, give the user and audience an idea of how that score compares to the injuries and checklist scores of 1500 operations at one facility. More research and epidemiological data is required to utilize this rating scale as a definite judgment of ergonomic risk. Therefore, it is currently utilized to merely compare operations and prioritise ergonomic actions required within each manufacturing facility. This thesis proposal will not in anyway try to validate or refer to the red, yellow and green ratings found at the bottom of the checklist.

The disclaimer box at the very bottom of the checklist form is there to describe that
the red, yellow and green rating is not the final determining factor related to ergonomic action. This information is at the bottom of the checklist to remind the user or reader that the ErgoMAP checklist is intended to be a rapid screening tool for use by persons with limited ergonomic training. Also, each risk factor line item with a repetition value of 2 or greater should be reviewed further, to determine the actual ergonomic impact based on applicable research for each specific situation.

The first investigation of checklist validity has taken place in the form of a literature review, aimed at determining the actual statistical and clinical evidence behind the trigger point guidelines outlined in the ErgoMAP.
Chapter II: REVIEW OF LITERATURE

The concept of identifying ergonomic risk factors has most commonly been categorized into three major groupings, known as force, posture and repetition (Kilbom, 1994; Konz, 1995). It should be noted that even though one word is used to describe these risk factors, it truly takes more than just any force, posture or repetition to create a risk of ergonomic injury, which is usually what is being referred to as “at risk”. In the development of the ErgoMAP checklist, recent research has been utilized to define each of these risks in terms of actual objective factors that can be either measured or identified from watching someone perform their work tasks. The combination of these three risk factors is often compared to the analogy of the fire triangle. Indicating that it takes all three of oxygen, fuel and heat/spark to create a fire, while at the same time assembly work requires high force, awkward posture and repetition/frequency to create what is commonly referred to as a cumulative trauma injury. Kilbom (1994), states that the three ergonomic risk factors, must occur simultaneously or during alternating tasks within the same occupational work for their effects to concur and interact. However, it has been found that certain ergonomic injuries can be caused by merely one of the three risk factors, if the severity of risk is very high. For a complete risk assessment of certain characteristics that may also lead to ergonomic injuries, a forth category titled “other” has been added to the checklist. This category is also to be added to the overall score and deals more with general conditions, such as vibration, that do not easily fall within the posture or force category. Thus, the aim of the ErgoMAP checklist is to combine the total
scores reported for each of the three categories, as they are related to specific repetition rates. This will promote and ensure the simultaneous consideration of force, posture and repetition through the preliminary ergonomic analysis of automotive manufacturing operations.

2.1 Repetition Criteria

For the purpose of relating repetition exposure to the operation being observed, it is easiest for practitioners and/or checklist users to refer directly to the cycle time. This is due to the fact that most manufacturing operations that will be evaluated using this checklist are broken down into specific cycles that occur in the same amount of time, every time across the entire work shift. In fact, research indicates that the concept of “repetitive work” refers to similar work tasks being performed again and again, and is defined by the duration and frequency of the work cycle being performed (Kilbom, 1994). The ErgoMAP checklist has used a review of research to apply a scoring system to the number of times a task is completed within each cycle, depending on the specific cycle time within a certain range (Chaffin, 1973; Genaidy and Al-Rayes, 1993; Kilbom, 1994; Kilbom and Persson, 1987 and Silverstein, et al. 1986). The ranges were developed using two methodologies. First, it was found that, within the company, work cycles often fall within three specific ranges of time. For work in power train, stamping and component assembly plants most cycle times fall between 14 to 22 seconds. Whereas for assembly facilities there are two, major line speeds. Some plants utilize between 42 to 47 second cycle times, while other plants with lower production rates work between 76 and 98-second cycle times. With these three distinctly different times per cycle, it was useful to separate the criteria of repetition to allow these cycle times to fit. Most of the literature
utilized to develop the action limit criteria for each of the risk factors was based on a 
repetition rate of one per minute. Therefore, this repetition was used as the nominal value 
for repetition at a score level of 2. As line items are performed greater or less than once 
per minute, the scores were adjusted around the nominal value of two. This repetition 
scoring system is also supported by a summary of literature by Kilbom (1994) that 
indicates cycle times of 30 seconds as either repetitive or highly repetitive.

2.2 Force Criteria

2.2.1 Two-handed lift greater than 20 lbs

Lifting is the most common type of manual material handling that is associated 
with ergonomics. Lifting is a physical task completed by a large number and variety of 
material handling and assembly operators in many different ways throughout a 
manufacturing facility. The ideal lift consists of having the knees slightly bent with the 
back in the neutral curve and the hands grasping symmetrical hand, holds less than 20" 
from the operator's center of gravity (Eastman Kodak, 1983). Unfortunately the 
environment we work in does not always allow an operator to lift a load within these 
ideal parameters. Even in the ideal situation, lifts that involve loads greater than the 
allowed maximum capacity of 75% of the female working population, may lead to 
ergonomic disorders if done repetitively (Snook and Ciriello, 1991). Therefore, it is 
essential to check off the correct repetition rate.

According to studies performed by Snook and Ciriello (1991), the maximum 
acceptable cyclic two-handed lift is 20 lbs. This recommendation accommodates 75% of 
the working female population and over 90% of the working male population. This data
was derived from experimental conditions lifting an object positioned 19 inches away from the body once every fourteen seconds from floor level to knuckle height. As taken from the Liberty Mutual lifting tables, which offer a set of guidelines in table form designed to allow the user to choose shop floor parameters to compare them with action limits consistent with the psychophysical worker capabilities (Snook, 1987).

This is consistent with the Revised NIOSH Equation, which calculates a recommended weight limit (RWL) of 20 lbs (Waters, et al. 1993), when lifting an object from 11 inches to 30 inches above the floor at a horizontal distance of 13 inches anterior to the subject’s center of gravity, with a frequency of two lifts per minute. The initial vertical height of 11 inches was chosen to represent the lowest lift scenario seen on a manufacturing shop floor, as even the lowest loads are usually 4 inches high and resting on a 7-inch plywood pallet. The final distance of 30 inches allows for close to a 20” lift, which is would be considered above average in a manufacturing environment. The frequency of two lifts per minute or one every 30 seconds was chosen to represent the frequency used in the Snook equation. This assumes good hand coupling to the load, no twisting while lifting, and that the operator continues to lift throughout the eight-hour work shift. The RWL represents a weight that 90% of the male working population can lift safely (Waters, et al. 1993). Therefore, the maximum cyclic two-handed lift utilized for the checklist is 20 lbs. This will reduce high back and shoulder forces.

The lift distance and reach parameters were chosen in the Snook tables and the NIOSH equation to represent very common types of lifting scenarios found in many manufacturing situations. The floor to knuckle lift also allows the checklist user to be sure that the weight limit utilized in the checklist was derived from a challenging lifting
condition. For a trigger point checklist aimed at raising red flags, it is better to err on the side of being more conservative. The frequencies were chosen to reflect and accommodate cycle time B from the checklist, so that either one of the three cycle times chosen will be accurately weighted from the base line of at least one lift every 30 to 60 seconds. This way, the score of 2 becomes the baseline for repetition scores and lifting more or less than this amount is equated accordingly for all other cycle times and repetitions identified.

To further substantiate this 20 lb value, it was also found by Mital (1984), to be the maximum acceptable weight to be lifted by female workers for 8 hours. With a 45.72 cm (17.5") box width and a repetition rate of 4 lifts per minute for floor to knuckle lifting the mean female worker could psychophysically lift 10.52 kg (23.5 lb). However, using the standard deviation of 2.64 kg the 75th percentile value is 8.71 kg (19.5 lb) (Mital, 1984; and Mital, 1984b). Thus, the approximate lifting guideline of 20 lbs is representative of 75% of the female working population for frequencies greater than two lifts per minute. The higher frequency of lifts was chosen from the Mital data to show that 20 lbs is substantiated by research through a wide range of lift frequencies.

It has been stated in ergonomic research that lifting outside this risk factor limit can cause over exertion, fatigue, increased oxygen consumption, and heart rate and injury to the tendons and ligaments surrounding these joints (Snook, 1987). The user of the checklist will be required to know the weight of the part that is being lifted. If the same type of part has a different weight, depending on the model number or different vehicle requirements, the heaviest weight is used. It should be noted that when awkward body postures or handholds are required for the lift, the 20 lb action limit might not be
conservative enough to eliminate ergonomic risk (Mital, 1984; and Waters, et al. 1993). If an operator is required to lift an object with one hand, a common rule is to use fifty percent of the guideline for two hands as the one handed risk factor determinant.

2.2.2 Two-handed carry greater than 30 lbs

Carrying is also a very common type of manual material handling. When done properly, and within certain weight restrictions, it can be a very safe and effective way of transporting material. Often, an operator is forced to carry an object at chest level due to space constraints or merely because the lift origin and destination points are high. As cited in Snook (1978) the average acceptable load for an object increases at knuckle as compared to chest height. Therefore, the design of the carry should allow material to be between elbow and waist height, and as close to the body as possible.

According to studies performed by Snook and Ciriello (1991), the maximum acceptable cyclic two-handed carry is 30 lbs. This recommendation accommodates 75% of the working female population and over 90% of the working male population. This data was derived from experimental conditions of carrying an object at elbow height over a distance of 28 ft. Female “elbow height” chosen from the Liberty Mutual table for carrying was 105 cm (Snook and Ciriello, 1991). The 30 lb guideline was taken as an average value between the values found at two different lifting frequencies. For the parameters stated above, an action limit of 13 kgs (28.6 lbs) and 14 kgs (31 lbs) were found for repetition rates of one carry every 24 seconds and every 1-minute respectively. Many carrying tasks do not require lifting if the load is delivered to the operator at carrying height, requiring very little vertical movement. Consequently, the biomechanical stressors are different for carrying tasks than for lifting tasks and a higher load is
acceptable. The psychophysical element of the research completed to obtain this 30 lb value allowed the subject to monitor his or her own feelings of exertion or fatigue, and adjust the weight or force of the object accordingly. Therefore, the maximum cyclic two-handed carry guideline used for the checklist is 30 lbs (Snook and Ciriello, 1991). Working outside these limits has been shown to cause over exertion, fatigue, increased oxygen consumption, raised heart rate and injury to the tendons and ligaments surrounding these joints (Snook and Ciriello, 1991).

Carrying greater than 30 lbs. contributes to increased operator fatigue as both the muscles of the upper and lower extremities are working at a greater percentage of their maximum voluntary contraction. This may lead to decreased control of handling objects, which contributes to part slippage and ultimately increased product defects (Kroemer and Grandjean, 1997).

2.2.3 Two-handed horizontal push or pull greater than 44 lbs initial or 24 lbs sustained

Horizontal push / pull tasks are utilized in many different ways and while interfacing with many types of apparatus and equipment throughout an assembly plant, for both one handed and two handed applications. From pulling a heater hose, to pushing grommets through a floor pan, all are considered push or pull tasks. Posture, force and repetition are all important variables to determine the acceptability of a push or pull task. This line item will allow the checklist user to identify either initial or sustained forces utilized to start or continue a force to install or maneuver various objects in numerous situations.
The above values were taken from the same quadrants in the Liberty Mutual push and pull tables respectively (Snook, 1978). A 7.6 m (24 ft) push and pull value was utilized due to the fact that most assembly operations utilized, at the company for which the checklist was developed, are commonly 20 linear feet in length. Therefore, an operator could potentially push or pull an object no more than half that distance twice per cycle, or 20 cumulative feet per cycle. These are above average shop floor parameters taken from observations from an automotive assembly plant floor. Although this guideline in the checklist will be used for many push and pull scenarios that travel a much shorter distance than 20 ft, it was utilized to accommodate greater than the average push or pull distance reviewed with automotive manufacturing operations. The hand height chosen from the tables was 135 cm (51”), because it was the worst-case distance within all other variables used for the maximum acceptable force in pulling situations. The percentage of the population chosen was 75% female, due to this being a corporate standard for the company in which the checklist was developed.

According to studies performed by Snook and Ciriello (1991), the maximum acceptable force to initiate a push is 44 lbs. and the maximum acceptable force to sustain a push is 24 lbs. This recommendation accommodates 75% of the working female population and over 90% of the working male population. This data was derived from experimental conditions of pushing once every two minutes with the handle at shoulder height over a distance of 24.7 ft. Identifying and eliminating initial and sustained push forces completed at the cycle times available in the checklist, may reduce the occurrence of excessively high force wrist, elbow, shoulder, low back, and lower extremity exertions. Each of these joints participates in pushing or pulling. Snook (1978) states that
having operators perform a cyclic two hand push/pull beyond these limits has been shown to cause over exertion, fatigue, increased oxygen consumption, raised heart rate and injury to the tendons and ligaments surrounding these joints.

2.2.4 Two-handed vertical push or pull greater than 25 lbs

Vertical forces can be exerted on objects without it being considered a lift at many different hand heights and orientations. In automotive assembly tasks, many operators are required to pull down or push up on trunks, lift-gates and hoods. The manipulation of articulating arms or ergonomic lift devices often requires an element of vertical pushing or pulling to control and initiate movement. Sometimes, tools that hang on balancers also require a pull down motion that is much easier to physically perform than actually lifting the object through space. However, it is still important to have a proposed action limit or guideline to identify risk and compare the physical requirement to actual ergonomic research.

In a reference table adapted from Yates, et al. (1980), Eastman Kodak (1986) illustrates that the maximum allowable forces to pull down on objects, such as chain hoists, are much greater than that allowed to pull or push up on objects at either shoulder or elbow level. According to Eastman Kodak (1986), the average operator can pull up 33 lbs and 17 lbs of force from elbow and shoulder heights respectively with the palms facing up and the operator in a standing position. To utilize the 17 lbs guideline would probably be too conservative, considering the fact that this line item is geared more towards the pushing and pulling forces that would be viewed as different from lifting. According to a study of female college students by Yates, et al. (1980), the average static lifting strength for the back, arm and shoulder muscles was 103.9 N or 23.5 lbs of force.
This force was applied at a 134 cm (53") vertical hand height above the floor and horizontal distance of 18 cm (7"). Therefore the mean value of 25 lbs found between the above two guidelines will be utilized (Eastman Kodak, 1986 and Yates, et al. 1980). This guideline can be compared to the initial force line item of 44 lbs utilized in F3 for two handed horizontal pushing and pulling.

Most assembly tasks, that require a vertical pushing or pulling, are completed across short travel distances, usually less than three feet. This 25 lb action limit to be utilized as a trigger for further review should be less than the initial horizontal push / pull force guideline of 44 lbs. Considering the fact that horizontal forces allow for greater utilization of larger muscle groups in the back and chest than the primary shoulder and arm exertions required for most vertical forces.

2.2.5 One-handed lateral push force greater than 15 lbs

This line item was designed to detect excessive force application for a one handed push force applied perpendicularly or across the body. This type of push force is seen quite frequently on the shop floor when operators are working on parts and elements inside the vehicle, while standing on the outside. For a transverse or lateral force, applied horizontally across the body, the recommended guideline is 15 lbs (Eastman Kodak, 1983) as found in a study by Kamon and Terrell (1979) of the Eastman Kodak Company. The value of 15 lbs can also be used if an operator is exerting a pull force across this same plane of motion. The posture and arm movement that should be recognized occurs
when the arm is extended out in front or to the side of the body and the force is applied at right angles in a line from the shoulder to the grip.

This action limit has been chosen as the maximum lateral force applied by a person with the arms fully extended in front of the body due to the fact that, in this raised arms and elbow extended posture, the force generating capabilities of the upper limb muscles are limited. Also, this posture engages the ligaments and small muscles surrounding the shoulder causing pain and discomfort to those tissues if prolonged or repeated. During high shoulder force exertions, the ligaments that join bone structures and a small group of muscles called the rotator cuff can be injured, particularly when non-neutral postures are involved (Sommerich, et al. 1993). Therefore, the maximum lateral forces applied horizontally at full arm’s extension in front of the body should be limited to 15 lbs.

2.2.6 Use of a hand / power tool greater than 5 lbs without a balancer

This checklist will be utilized to analyze numerous operations where power tools are operated with the worker’s arms in an outstretched position, or in other postures where the fatigue of the forearm and shoulders is a potential risk. In a study by Mital and Kilbom (1992), it was determined that the effective weight of a power tool should not exceed 2.3 kg (5 lbs) and 1.75 kg (3.8 lbs) for precision tools. “In general, any tool weighing more than 2.3 kg (5 lb) that has to be operated while supported by the arms and has to be held out from the body is likely to fatigue the small muscles of the forearm and shoulders” (Eastman Kodak, 1983).
2.2.7 Trunk rotation with a weight greater than 10 lbs

This line item addresses one of the primary rules of ergonomics, that states on a repetitive basis, operator should avoid trunk twisting with a weight whenever possible (Sanders and McCormick, 1993). In most courses, seminars or reading materials on the basics of ergonomics you will see this line item as one of the golden rules. This is a motion that can often be eliminated through proper training and lifting techniques. It has been found, by Mital and Fard (1986), that asymmetrical lifting leads to lower maximum acceptable weights of lift, greater intra-abdominal pressure and greater electromyographic activity of erector spinae and external obliques compared to sagittal lifting. It is the external load of greater than 10 lbs, combined with the rotation of the lumbar region that must be avoided.

According to Konz (1995), twisting when lifting increases the risk of low back pain and causes more fatigue than when doing a similar amount of work without twisting. There are a limited number of psychophysical studies that address the relationship between lifting loads while twisting or away from the sagittal plane. Of the limited number of psychophysical studies available, all have reported a decrease in maximum acceptable weight (8% to 22%) and a decrease in isometric lifting strength (42%) for asymmetric lifting tasks of 90 degrees compared with symmetric lifting tasks (Garg and Badger, 1986; Garg and Banaag, 1988; Mital and Fard, 1986; and Waters, et al. 1993). With those studies in mind, the 1991 NIOSH Lifting Index committee recommended that an asymmetric multiplier of 30%, be established for lifts with asymmetric twists of 90 degrees (Waters, et al. 1993). However, other pre-existing data from Warwick et al.
(1980) reported up to a 50% decrease in static strength when the subjects were rotated into 90 degrees of asymmetry.

It should be noted that this checklist does not ask the user to determine the degree of asymmetry, nor identify whether it is a static or dynamic motion. Based on the research noted above by Sanders and McCormick (1993) and Mital and Fard (1986), which denotes the high level of risk for any amount of twisting, the 10 lb criteria was chosen to represent 50% of the 20 lb guideline selected for symmetrical lifting situations in line item F1 for symmetrical two-handed lifts.

2.2.8 Power tool torque rating for a right angle tool greater than 37 ft-lbs, or a pistol grip greater than 26 in-lbs.

Assembly operators in a manufacturing environment are often required to utilize power hand tools to complete the rotational securing of threaded fasteners, such as screws and bolts. Also, pneumatic nutrunners are very popular, as estimated by Ford to make up nearly 75% of all power hand tools utilized throughout the corporation (Radwin, et al. 1989). Silverstein, et al. (1987) reports that power hand tool operation is a common risk factor for cumulative trauma wrist disorders. Thus, it is important to be aware of the amount of either horizontal or rotational force required by the operator to apply to the handle of the tool during its torque reaction phase.

Power hand tools go through three major phases (pre-start, run-down and torque-reaction) from the start to the final secure of a common fastener. The pre-start phase refers to the moment in time where the operator is applying a grip force to align and hold the tool in place prior to trigger activation. The operator is required to apply a constant grip force to the trigger during the run-down phase, which is commonly less than 4.5 lbs.
on most power hand tools (Lindqvist, 1997). Then finally, in the torque-reaction phase, the spindle torque increases linearly from zero to its maximum and back to zero. The most common handle configurations of the power tools studied using this risk factor checklist have been pistol grip, and right angle.

The right angle tool is normally operated with two hands. One hand placed at the head of the right angle nutrunner, guiding the socket over the fastener and applying a slight driving force. While this is happening, the other hand is at the handle of the tool, assisting in supporting the weight of the tool and applying most of the counter force to the tool upon the reaction torque phase. Radwin, et al. (1989) completed a study to investigate the effects of right angle nutrunner operation on the extrinsic hand flexor and extensor muscles in the forearm. Four male and one female (right-handed) subjects participated in the study, with pneumatic power tool experience ranging from zero to 30 years. Four different nutrunners were utilized for the purpose of the study, each with a different weight, handle length, speed and peak torque (Table 1).

<table>
<thead>
<tr>
<th>Tool</th>
<th>Length cm (inches)</th>
<th>Weight kg (lbs)</th>
<th>Speed rpm</th>
<th>Average Peak Torque Nm (ft-lbs)</th>
<th>Peak horizontal force required at the handle in N (lbs force)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>34 (13.4)</td>
<td>2.15 (4.7)</td>
<td>752</td>
<td>29.7 (21.9)</td>
<td>87 (19.5)</td>
</tr>
<tr>
<td>2</td>
<td>37 (14.6)</td>
<td>2.38 (5.2)</td>
<td>390</td>
<td>46.7 (34.4)</td>
<td>127 (28.5)</td>
</tr>
<tr>
<td>3</td>
<td>39 (15.4)</td>
<td>2.49 (5.5)</td>
<td>460</td>
<td>58.9 (43.4)</td>
<td>150 (33.7)</td>
</tr>
<tr>
<td>4</td>
<td>50 (19.7)</td>
<td>2.6 (5.7)</td>
<td>280</td>
<td>99.4 (73.3)</td>
<td>201 (45.2)</td>
</tr>
</tbody>
</table>

(Developed from information in Radwin et al, 1989).
Forearm flexor RMS EMG signals were scaled according to the force calibration regression coefficients for each subject and measured to estimate grip exertions through all three phases of nut runner operation. They found that the average flexor RMS EMG amplitude was more than four times greater in the torque-reaction phase, then in the pre-start phase, and accounted for 97% of the peak resultant hand force (Radwin, et al. 1989). This finding showed that reaction force was the greatest force component acting against the hand, as compared to the trigger and hold forces involved with nutrunner operation. The Radwin, et al. (1989) study indicates that “for females having 95 percentile stature (173 cm, 91 kg) 95% are predicted capable of producing shoulder strength required for tool 1, 85% for tool 2, 76% for tool 3, and only 46% for tool 4.” In fact 91% of the 95 percentile males were predicted to be capable of producing shoulder strength for tool number 4. Therefore, to accommodate for a greater percentage of the population, the average peak force of 73.3 ft-lbs was reduced by 50% and utilized as the trigger point for this checklist line item, with respect to right angle power tools. According to the results indicated above, 37 ft-lbs would allow for roughly 80% of the female population to be capable of producing the necessary shoulder force.

To determine the recommended amount of torque reaction rating for a pistol grip tool, the maximum supination strength from a study of 81 female college students was taken. This study was completed by Asmussen and Heebol-Nielsen in 1961, and was adapted from Eastman Kodak (1986). As a pistol grip power tool completes its run down phase and its final torque the gun will turn or ‘kick’ in a counter clockwise direction. Assuming that the pistol grip tool is being operated in the right hand, the operator must apply a clockwise force to the handle of the tool. Therefore, the isometric forearm, power
grip supination strength results from Eastman Kodak (1986) emulate the force exertion about the wrist required to control the dynamic torque reaction of a pistol grip power tool, both air and electric. The average torque from the female supination strength expressed was found to be 8.6 Nm. In fact, the average isometric pronation strength for the same population was also 8.6 Nm. Thus, even if the operator is left hand dominant or is forced to utilize their left hand, the pronation strength guideline can be applied for a force in the clockwise direction. Due to the fact that this checklist is trying to monitor and highlight the ergonomic implications of repetitive assembly tasks at a nominal repetition rate of one per minute, 50% of the maximum voluntary supination strength was utilized to accommodate for cumulative trauma affects to the intrinsic wrist and forearm musculature. Therefore, 4.3 Nm (38 in-lbs) is the trigger value for assigning a repetition value to this line item of pistol grip torque control. The nominal or target torque rating for the tool should be found and utilized to determine the reaction force, not the maximum or minimum torque ratings.

2.2.9 Pinch grip of greater than 2 lbs

Pinch gripping is an extremely common method of transporting, positioning and placing objects during many different types of assembly and manufacturing tasks. Based on experience as an ergonomics practitioner and checklist user the easiest way to determine pinch grip force is to assume that the weight of the object being pinched is close, if not equal to the amount of force required to pinch it. It would be unrealistic to believe that a checklist user would have the time and or the resources to determine the exact force in pounds of each pinch grip identified. Often the type of pinch grip that is required for a given task is difficult to determine due to the fact that the speed and
preferred method can vary significantly between operators. Therefore the following research utilized to determine acceptable pinch grip norms was combined and a mean was found between three different types of pinch grips. Palmar pinch grip is the motion of squeezing an object between the pads of the index and middle fingers with the thumb pad. Key pinch is the application of force required to hold an object between the thumb pad and the lateral aspect of the middle knuckle of the index finger. Finally, tip pinch, the weakest of the three is the motion and force required to hold an object between the tips of the thumb and index fingers.

Mathiowitz, et al. (1985) completed a study aimed at determining the maximum pinch grip strength for the three different types, using 628 volunteers aged 20 to 94 years. For each of the three pinch grip tests, the subjects were seated with the same upper arm, elbow and wrist postures throughout the testing. The elbow was flexed at 90 degrees and the wrist was dorsi-flexed between 0 - 30 degrees and ulnar deviated between 0 -15 degrees. A standard Jamar dynamometer was utilized as well as very standardized instruction for each of the subjects. As described above, the average maximum strengths for the three different types of pinch grips were combined using the mean data from all age groups. The mean pinch grip strength found with the right hand, for right hand dominant females for the tip, key and palmar pinch grips was 11.4, 16.3 and 16.3 pounds respectively (Mathiowitz, et al. 1985). The average between these three types of pinch grip means was 14.7 lbs with an average standard deviation of 3.2 lbs. The mean and standard deviation of the three grip forces combined, along with the universal z-score for the 25th percentile was utilized in a calculation to determine the pinch grip strength for 75 percent of the female population studied. The value determined from the calculation was
an average of 12.6 lbs maximum pinch grip force across the three different types of
pinch. This average will be utilized due to the fact that the three different types of pinch
grips are often required and interchanged by operators in many manufacturing / assembly
tasks. It should also be noted that for most pinch grip tasks witnessed in the average
automotive assembly facility, cotton gloves are worn to protect operators from the oil and
grease associated with the fasteners and tools utilized. It was found in Eastman Kodak
(1986), from a study by Susan Rodgers that the average maximum isometric grip strength
is reduced by 26% when a subject is required to wear cotton gloves. Therefore, the
maximum combined pinch grip force from the Mathiowetz, et al. (1985) study of 12.6
lbs, was reduced to 9.3 lbs using the grip strength reduction percentage above. Finally,
Konz (1995) reports that muscles of the forearms, fingers and hand cannot maintain a
contraction level in excess of 20% of their strength for more than a few seconds without
significant fatigue. Consequently, a 2 lb force guideline for a pinch grip is derived to
identify and minimize operator fatigue, pain or discomfort and enhance recovery needs.

In comparison to other research this 2 lb pinch grip guideline is identical to the
requirement utilized by Eastman Kodak, (1986) which states, “for repetitive operations
that require finger pinches, keep the forces below ten Newton’s (2.2 lbf)”. This
information was derived from Asmussen and Heebol-Nielsen (1961), and represents 20
percent of the weaker operators’ maximum pinch grip strength. Thus, the above guideline
of 2 lbs found in the strength data will be utilized for this line item in the checklist.
2.3 Posture Category

The body is capable of moving through and working in a great number of postures and ranges of motion with each posture. The body has a neutral or anatomical posture for each joint. It is this neutral posture that in most joints allows for the most comfortable feel and highest amount of force production available. However, many times a manufacturing worker is required to repetitively work outside of this nominal or neutral joint range of motion. A strain is placed upon the muscles and ligaments along with a stretching of the nerves and blood vessels, when mechanical leverage outside of the normal range occurs. This can affect the function of the nerve and eventually interfere with work performance and energy output. These factors must be considered in the detailed analysis of upper and lower extremity work performance (Feldman, et al.1983). Many clinical and empirical ergonomic studies have shown that non-neutral upper extremity posture, influenced by workplace layout, job and tool design is a prime factor in the development of musculoskeletal injuries (Feldman, et al. 1983; Hagberg, 1981; Hagberg and Sundelin, 1986; Sommerich, et al. 1993 and Wiker, 1989). In fact, Wiker (1989), states that, “from an occupational perspective, the incidence of temporary and chronic musculoskeletal pain may be most attributable to muscle and connective tissue strain caused by non-neutral posture”.

The entire checklist will attempt to combine and consolidate the effect of all three primary ergonomic risk factors. However, it has been found that even without great external loads the force on the joints performing non-neutral postures can indeed create musculoskeletal risk. As stated by Chaffin (1973), “Muscle contractions need not be strong to impede muscle perfusion and provoke signs of localized muscle fatigue”. Wiker
(1989) also notes that voluntary isometric contraction levels as low as 10-20% of the maximum contraction capability have interfered with perfusion in muscles of the upper extremities. Therefore, the posture category will play an important role in the determination of overall risk factor value for a given operation.

2.3.1 Horizontal reach distance greater than 20"

Reach distances greater than 20" from the operator's center of gravity will generally add force or stress to two joints or body regions. The first joint affected is the shoulder, with bursitis being a common injury type caused by repetitive reaching in front of the body (Sommerich et al, 1993). Secondly, the lower lumbar region of the back experiences a significant increase in compressive forces on the inter-vertebral disc at L5/S1 when the operator's hands are forced to reach greater than 20 inches. Usually an operator is forced into some degree of back flexion to meet a reach requirement of 20", depending on the workstation layout. It is a well-known biomechanical fact, that even as the smallest load is moved from the operator's center of gravity, the axial compressive force or stress on the spine is increased proportionally with the reach distance. Also, psychophysical data consistently indicates that as the load is moved horizontally from the spine, the acceptable load decreases proportionately (Snook, 1978; Snook and Ciriello, 1991 and Waters, et al. 1993).

According to Eastman Kodak (1983), 95% of the population is able to functionally reach up to 20 inches when the hand height is between 44 inches and 49 inches above the standing support surface. The reason for choosing this numerical value is three fold. First, most assembly work that is completed on a repetitive basis will fall within these vertical heights measured from the worker supporting surface, as stated
above. Also, the 5th percentile data of 20 inches was chosen to try and accommodate as large a representation of the population as possible. It is often necessary to determine the limiting (5th percentile) size and shape of the workspace in terms of the maximum reach envelope to arrive at specifications for design of an industrial workstation that can be operated by the majority (95%) of the population (Sengupta and Das, 2000). Finally, in general terms, 20 inches is a very simple and memorable number to have depicted on a checklist for the user. Therefore, reaches beyond 20 inches with or without an external load should be minimized (Eastman Kodak, 1983). This will help to reduce any awkward elbow, shoulder and back postures.

This number is also supported by recent forward reach data collected by using a computerized potentiometer measurement system of 84 different reach end points of subject’s hands in both a seated and standing position (Sengupta and Das, 2000). There were 40 adult male and 40 adult female subjects that were selected randomly using a stratification plan to represent the adult North American population. For the 50th percentile female data, the mean maximum reach envelope for 168 different vertical and lateral reach end point combinations was 52.76 cm or 20.2 inches (Sengupta and Das, 2000). Thus, utilizing data from the average female population and a very large range of motions, the 20” criteria continues to be a consistent maximum value.

2.3.2 Back flexion greater than 45 degrees

One of the most common positions associated with clinical low back pain and injuries for assembly workers is a stooped or bent over posture. This posture can be dangerous if held for both, short or long periods of time, depending on the amount of weight being manipulated while bent over. With a bent over posture at the trunk, the
amount of compression on the L5/S1 joint increases as well as the risk of low back pain (Andersson, 1981 and McGill and Norman, 1986). It is the muscles, ligaments and tendons surrounding this joint that are required to hold an eighth of the upper body, along with an external load being held (McGill and Norman, 1986). Material handling motions often required an operator to occasionally bend deep into a bin or rack to obtain the last few remaining parts. Working on a vehicle assembly line where objects must be secured to the floor pan while the carrier is below waist height is also a common cause of stooped posture.

A case-referent study completed by Punnett, et al. (1991) found that there is a strong and consistent relationship between occupational exposure to non-neutral trunk postures and musculoskeletal disorders of the back. This study actually took place at an automobile assembly facility with similar division and operation descriptions that will be reviewed with this checklist. A strong increasing trend in risk was observed with an increase in the degree of flexion from the values of bending that they considered “mild” (20° to 45°) and “severe” (45° and greater). For the investigation the researchers defined the “cases” as workers who filed new reports of back disorders during the two-year study period. Whereas the “referent” workers were those who did not report any back disorders to the medical department during the study period and who had no signs or symptoms of back disorders at the interview and examination (Punnett, et al. 1991). It was found that cases were roughly six times more likely when work was performed in forward flexed postures greater than 45° (severe), when compared to the referent workers. Due to the minimal low back cases with back bending angles less than 45°, it seemed as though this posture was the cut off value or guideline to utilize when reviewing repetitive automobile
assembly operations. Thus, the above findings coupled with an easily identifiable value of 45°, makes this checklist line item both friendly to the user and the operator being studied.

2.3.3 Neck flexion greater than 30 degrees or extension greater than 20 degrees

A very common complaint heard from office/clerical workers, sewing machine operators, or assembly line employees working with small component parts, has been of upper shoulder and neck discomfort. Ironically, neither of these occupations typically requires high amounts of external shoulder force related to pushing, pulling or lifting heavy objects. However, each of these three example situations, noted above, do require the operator to hold their heads in a tilted forward position in order to see what they are doing. Therefore, this is one of those line items where posture alone can create operator fatigue and discomfort and should be given a value based on the repetition combined with the degree of motion.

Chaffin (1973) determined that a maximum inclination angle at the neck should not exceed 30 degrees for a prolonged period of time. The study of five, female subjects was conducted to ascertain the time it would take them to reach the Class II fatigue states when holding their heads at specific degrees of tilt for 50-minute intervals, with a 10-minute rest between intervals. The results clearly indicate that tilting the head more than 30 degrees greatly increases the neck extensor fatigue rates and spine compression. Chaffin (1973) also states that a high forward tilt can create forward spine compression to increase. Compression at the cervical spine can also occur with the neck bending in extension. Mechanical stress that precipitates the clinical variety of headache can be overhead work in which the sternocleidomastoid muscles checkrein the backward tilting
of the head (Travell, 1967). This research did not indicate the exact level or degree of
backward neck tilt that may precipitate headaches, however the diagrams show very little
range of motion (approximately 20 degrees or less). Also, it should be noted that the
RULA indicates that a high risk is present with neck extension of any degree
(McAtamney and Corlett 1993).

Thus, the checklist will combine repetition values to identify and prioritize
ergonomic risk when operations are associated with degrees of neck flexion and
extension of 30 and 20 degrees respectively. It should be fairly simple for the trained
checklist user to recognize both ranges of forward (flexion) and backward (extension)
neck bending.

2.3.4 Trunk or neck side bent and or flexed, plus twisted

The association between low-back symptoms and frequent bending/twisting is
difficult to evaluate separately. It is often difficult to visually indicate the degree to which
someone is both side bent and twisted. However, the combination of the two postures is
the most frequently reported cause of back injuries in England, (Troup, Roantree and
with this type of motion comes in two directions. First, the lateral or side bend places a
downward force on one side of the disc or discs. While the rotation places a shear force to
the disc between any two vertebrae, depending on the height of the rotation and the
muscles involved.

In a case-referent study completed by Punnett, et al. (1991), the researchers found
that there is a strong and consistent relationship between occupational exposure to non-
neutral trunk postures and musculoskeletal disorders of the back. For the investigation,
the "cases" were defined as automobile assembly workers who filed new reports of back disorders during the two-year study period. Whereas the "referent" workers were those who did not report any back disorders to the medical department during the study period and who had no signs or symptoms of back disorders at the interview and examination (Punnett, et al. 1991). It was found that cases were roughly five times more likely when work was performed in laterally bent and/or twisted postures, compared to the referent group.

Eklund, et al. (1994), indicates that the sideways sitting of forklift drivers, with the neck bent to the side and rotated backwards for driving in the reverse direction, can be one source of musculoskeletal problems in driving tasks. This finding comes from a study using an electrogoniometric measurement system, designed to record postural degrees of motion of forklift, crane and forestry machine drivers who performed maximal voluntary movement of the head and neck in three planes. The three planes of motion measured were flexion and extension, left and right side bending, as well as left and right rotation. Even though this study proclaims that the type of data should not be used as ergonomic guidelines, it is obvious that the combination of neck flexion and rotation is one of the key risk factors related to high postural loading of profession drivers of work vehicles (Eklund, et al. 1994). In a study by Wikstrom, et al. (1992) measuring both vibration and subject discomfort as it related to three different postures of the trunk and neck, the distribution of discomfort for the different body parts were higher in the neck and shoulder for twisted postures. Rotation of the head only, without vibration, corresponded approximately to the level of discomfort and the EMG-activity for a high
level of whole-body vibration (1.0 m/s²) with a symmetrical sitting posture (Wikstrom, 1992).

Therefore, without any specific guidelines as to the degree of this posture that would indicate a risk, the research presented above will be utilized to determine that any combination of lateral bending and twist should be highlighted and compared with repetition by the checklist user.

2.3.5 Shoulder abduction greater than 90 degrees

Shoulder abduction is a lateral movement of the upper arm, with the hands moving out the side and away from the operator’s center of gravity. “Abduction moves the center of mass of the upper limb away from the body and thus increases forces acting on the muscles of the shoulder joint, such as the trapezius” (Tichauer, 1966). It has been witnessed in many automotive assembly tasks that operators use this shoulder abduction posture to complete required elements both inside and outside the vehicle. In a study by McAtamney and Corlett, (1993) the RULA survey method attaches an additional risk value to all shoulder postures requiring abduction at any level. Stress on the scapular muscles and trapezius will vary with the degree of abduction from the center of the body. In fact, a shoulder abduction angle of 40 degrees will stress the upper fibers of the trapezius roughly 8 times more than at an angle of 20 degrees (Tichauer, 1966). If method preference is the reason that operators complete an upper arm abduction posture of greater than 90 degrees, because it feels easier and quicker than moving in front of the applications, they should be made aware of the ergonomic risks of this posture. In fact many related tendon disorders of the shoulder and upper extremities, such as rotator cuff tendonitis, have been associated with repetitive arm motions involving abduction or
rotation of the shoulder (Sommerich, et al. 1993). Activities such as repetitive abduction have been known to hasten the cumulative micro trauma to the supraspinatus tendon (Owen, 1996).

In experiments by Wiker, et al. (1989) the sensitivity of speed-accuracy movement performance was measured and statistically compared to a wide range of hand locations and upper arm postures. Abduction of the arm resulted in statistically significant decrements in both vertical and horizontal axis movement performance. They believe that the main reason for the this finding is that abduction of the arm produces substantial co-contraction of the majority of the girdles agonist-antagonist muscle groups for purposes of limb and articulation stabilizations. They also found that increasing the hand elevation from 15 degrees to 60 degrees above shoulder level with the upper arm at 90 degrees of abduction, increased the times required to complete move and positioning elements by 15.3% and 26.5% for hand loads and duty cycles tested respectively. Hand loads or stylus weight and number of duty cycles per minute were two independent variables that were measured and compared to the shoulder postures tested (Wiker, et al. 1989).

Therefore, shoulder abducted postures become a risk factor for this checklist and are combined with repetition rate when the operator is required to work with the elbow at or above shoulder height and out to the side of the body.

2.3.6 Working with hands or arms behind the body

Through utilization of this line item on previous checklists throughout automotive assembly facilities, it has been determined that working with hands or arms behind the body is quite rare, with less than a 2% occurrence rate (See Appendix D). However, it
does occur occasionally, and when it is identified that an operator is required to reach
behind their body to obtain a tool or fasten a part, it usually highlights that there is
something fundamentally wrong with the design of the workstation. However, if the
workstation design allows the operator to work with their hands in front of them, and they
merely choose to reach behind, it should be explained to them that this type of posture
could lead to potential work related injuries of the lower back and upper extremities. If
required, this explanation can be placed inside a manufacturing work instruction or job
hazard analysis to remind the operator to not reach behind them. When working behind
the body, it is obvious that the complexity of even the simplest task becomes greater,
thereby increasing the duration of which the task is completed in.

Some of the postures that are utilized while reaching behind the body are shoulder
abduction greater than 45 degrees, cervical spine twisting, and trunk rotation. It has been
documented in numerous research articles that postures at these levels, which may be
caused by working with the arms behind the body, can lead to musculoskeletal or
repetitive motion disorders (Punnett, et al, 1991; Sengupta and Das, 2000; Sommerich, et
al. 1993 and Wiker, et al. 1989b). Therefore, it is important to ensure that the workstation
is designed to eliminate the opportunity for workers to reach behind their back, and if this
is not possible, the risk factor should be highlighted and combined with the appropriate
repetition rate.

2.3.7 Wrist flexion or extension greater than 45 degrees

The wrist is an incredibly mobile joint for its size, considering the fact that there are
nine bones and five tendons creating tunnels and pathways for nerves and blood vessels
to safely pass through. In many different types of assembly work the wrist is required to
be bent in one of two actions, which are referred to as flexion and extension. With the elbows at your side and bent at 90 degrees, flexion and extension is completed by bending the hands first towards and then away from each other, respectively in the sagittal plane. These bent wrist postures in either direction can be caused by a number of different variables related to the workstation design. For example, the operator’s hand height in relation to the angle or direction of motion can be one of many causes for a bent wrist. There is a normal range of motion that the wrist can move through without placing a stretch on the tendons of the joint. Many biomechanical researches indicate that working outside these normal ranges can lead to cumulative trauma disorders. Welch (1972), states that working with a bent wrist should be avoided due to the amount of static muscular work required to maintain the bent position. In fact it has been stated by Chaffin and Andersson (1984), that work involving repeated flexion and extension in extreme ranges can lead to the onset of carpal tunnel syndrome.

In a book by Kroemer, et al. completed in 1997, work by their staff in 1983 was summarized to find a guideline for the normal operating range that can be completed for the largest percentage of the population. The study by Kroemer (1997) was completed using 100 females ages 18 – 35. Each subject was measured with an electronic bubble goniometer and asked to move their limbs “only as far as comfortably possible”. The maximum ranges of motion for the 5th percentile of each group was used as a conservative measure for comparing a wrist flexed or extended posture with repetition. For 95% of the male and female population studied, the active wrist flexion was 51 and 54 degrees respectively, while for extension, 95% of the male and female population studied was found to have active wrist extension of 47 and 57 degrees respectively.
(Kroemer, et al. 1997). It is important for the checklist user to utilize both a conservative
guideline as well as a value that is easily identified in degrees of motion. Therefore, a
wrist flexion and extension value of 45 degrees was chosen to represent the research
stated above, as well as to utilize an identifiable range of motion. It is quite simple to
train a checklist user that 45 degrees in either direction is half of 90 degrees from neutral.
To reiterate the degree of motion value of 45 degrees that is highlighted as a risk factor
for this line item. It was found in a study by SUNYAB-I\E 1982/1983 as cited in Eastman
Kodak (1986), that isometric grip strength is reduced by 40% for wrist flexion at 45
degrees and 25% for 45 degrees of wrist extension. Thus, as the amount of strength
available is reduced with the wrist flexed or extended to 45 degrees, the hand will
automatically require greater force at the hand to control an object, as compared to the
force required while in a more neutral range of motion.

2.3.8 Wrist deviations, ulnar greater than 20 degrees or radial greater than 15
degrees

Ulnar and radial deviations are two more types of wrist movement like flexion
and extension that can be performed repetitively within a normal range of motion. To
remember and recognize these wrist deviations, it is important be familiar with the two
lateral borders of the hand. Those being the ulnar and radial borders, which reside on the
lateral side of the baby finger and thumb respectively. When the forearm is stable and the
hand moves to the ulnar side of the hand, this is known as ulnar deviation. When the
wrist is bent in the opposite direction or towards the thumb (radius), the posture is
referred to as radial deviation.
Also, like flexion and extension these two wrist postures that deviate the wrist in either direction can be created from numerous variables involved with the human, machine or human, workstation interface. Tool design and its interface between the hands will greatly affect the degrees of deviation required to manipulate the tool. For instance, the hand will tend to work in ulnar drift, with the utilization of common straight nose pliers, which will stress the extensor tendons and create lateral compressive stress between the bones of the wrist (Tichauer, 1966). These postures, when done repetitively can lead to cumulative trauma injuries such as tenosynovitis and peritendinitis, especially when combined with pinch grips (Chaffin and Andersson, 1984). However, for almost every tool that creates a wrist deviation now, there is another tool that is available or can be designed to comply with the anatomical structures of the hand. Reducing the degree of deviation at the wrist will in turn reduce the amount of compressive forces on the joints and contraction strength of the muscles.

However, unlike flexion and extension these two deviated postures allow for a much slighter degree of movement from the neutral position. As cited in Kroemer and Grandjean (1997) the normal range of motion for 95% of the male and female population studied by Kroemer, et al. in 1997 are as follows. For 95% of the male and female population studied, the active ulnar deviation was 22 and 19 degrees respectively. While for radial deviation, 95% of the male and female population studied was found to have active wrist extension of 14 and 17 degrees respectively. Therefore, with such a discrepancy between the two findings, different values will be utilized to highlight wrist for the two different types of wrist deviation. Repetition values will be assigned to the checklist by the user when deviations are identified in the ulnar and radial directions of
motion at 20 and 15 degrees respectively.

2.3.9 Pronation or supination of the hand against a resistance

Specific neuromuscular disorders have been linked and associated with this postural risk factor. Pronation and supination of the wrist alone have not been found to be the cause, but pronation against a resistance with a tightly clenched fist has been clinically proven to increase pain in the upper forearm (Feldman, et al. 1983). This type of pain is one of the most prevalent symptoms utilized to describe pronator syndrome, which has been associated with physical tasks that require pronation and external-internal rotation of the forearm. Feldman, et al. (1983) also eludes to the fact that pronation and supination of the wrist and forearm can and will most likely aggravate the prevalence of pronator and supinator syndromes, when combined with forceful finger flexion. The type of finger force that is related to the handling of power tools in a manufacturing or assembly type of setting.

“Workers performing tasks that place them at high risk for developing this syndrome should be cautioned against motions that require the use of high hand force simultaneously with a pronated forearm” (Feldman, et al. 1983). This research has led to the wording in the line item above that indicates an operator is being exposed to a risk factor of pronation or supination when the hand and wrist is working against a force or resistance, while in either of the two postures. The easiest way to describe pronation and supination is to first achieve a neutral wrist posture with the palms of your hands facing each other, while the upper arms rest against the sides of your body and your elbow is flexed at 90 degrees. Pronation and supination can be achieved when the palm of the hand is facing the ground, and the ceiling respectively.
Either of these postures should be highlighted as a risk factor and compared to the repetition associated with the task involved when they are combined with an application of force, including when the hand is holding an object with the fingers flexed around it. Re-orientation of fasteners or other objects related to the assembly task can often help an operator achieve the same goal with a limited amount of wrist rotation.

2.4 Other Risk Factor Category

2.4.1 Noticeably high, tool or floor vibration

This line item is designed to highlight whole body and or segmental vibration that may be felt by the operator, from the utilization of tools or through the worker-supporting surface that may provide a visibly detectable amount of vibration. The range of frequencies in which different body parts begin to react to vibration is between 2 to 200 Hz (Kroemer and Grandjean, 1997). With the time constraints and difficulty required to accurately measure and evaluate vibration, the checklist user should merely compare the visible amount of vibration at the tool or the worker supporting surface other human, machine interfaces throughout the facility. “Anyone who has been involved in vibration measurements knows that these are costly and difficult to perform in a laboratory, let alone in real work situations” (Lindqvist, 1997). For the most part automotive assembly facilities are utilizing pneumatic tools with enough internal dampening mechanisms that a tool without such vibration controlling devices should stick out like a sore thumb. Tools such as grinders, chipping hammers, riveters and worker supporting surfaces such as platforms that constantly shake or forklifts all provide noticeably high vibration between the machine and the human. Even if the checklist user was expected to measure vibration,
there is very little research that implicates an acceptable guideline or limit between the exposure – response relationship of vibration and the risk of injuries or musculoskeletal disorders (Burdorf and Swutse, 1993; Lindqvist, 1997; and Wikstrom, 1992).

However, many ergonomic books and research articles have alluded to the linear relationship between physiological stress and both whole body or segmental vibration. Thus, it was felt extremely important to highlight noticeable vibration between the worker and the tool and give it a score of 2, to be combined with the remainder of the checklist values, (Cole, 1982. Chaffin, et al. 1984; Kroemer and Grandjean, 1997; and Spaans, 1970). At the turn of the century many crude pneumatic tools such as cement drills, without the sophisticated internal vibration limiting devices that we have today, were linked directly to nerve disorders, such as Raynauds phenomenon. Although the potential still exists for this type of nerve related vibration disorder, most researchers in this field believe that the continuous vibration of tools mainly effect the bones, joints, ligaments and blood vessels of the body, rather than just the nerves (Spaans, 1970).

Results of an EMG study on the drivers of three different types of forklifts show a linear correlation between vibration level and EMG activity (Wikstrom, 1992). The EMG was taken from surface electrodes on four muscles, in the upper back and cervical spine area. The vibration measurements were taken by a round aluminum transducer placed under the ischial tuberosities of the seated subjects. Due to the fact that the muscular demands to control the forklift was very low, it is assumed that the linear relationship of vibration and EMG described above was the cause of the muscular force of the shoulders and arms. Discomfort ratings were also taken in this study using the Borg CR-10 scale. “At the symmetrical sitting posture, the rated acceptable exposure time was
approximately 5.5 hours at the vibration level of 1.0 m/s² for all three fork lifts” (Wikstrom, 1992). Therefore, the checklist user would be expected to highlight this risk factor with a yes (score = 2) if required to study forklift drivers.

The vibration source (pneumatic tool, forklift truck) is not always the only reason for musculoskeletal disorders related to vibration, as described in a research study of head and neck postures in forklift drivers by Eklund et al (1994), the unfavourable combination of neck flexion and rotation can increase vibration exposure to the head and neck. Similarly a study by Wikstrom (1992), showed that postural rotation of the head was as related to higher levels of EMG activity and subjective operator discomfort as was vibration at levels of 1.0 m/s². Wikstrom (1992) also concluded that there is possibly an increased risk of lower back disorders when prolonged sitting in unfavourable postures is combined with whole body vibration. Therefore, it is very important to include noticeable vibration in this preliminary screening tool, as it may help the user identify a combination of a number of other risk factors such as poor posture.

2.4.2 Climbing up 2 steps, a 7ft ramp, or into a vehicle once per minute

This is one of the more rare line items that you may never find when reviewing normal assembly operations. However, sometimes operators are required to climb a few steps, in and out of vehicles or up a ramp to a platform on a repetitive basis. It is often an unwritten rule in automotive assembly plants that an operator is required to climb into a vehicle no more than once per minute. In fact, many manufacturing design books and manuals recommend that all assembly work be completed from outside the vehicle, whenever possible (Konz, 1995; Eastman and Kodak, 1986; Kroemer and Grandjean, 1997). This is recommended due to the fact that climbing up a grade or steps can be an
extremely strong source of operator fatigue and high-energy expenditure. Assuming that an operator is required to perform other work elements within a given cycle, this level of repetitive climbing can lead to high-energy cost and ultimately operator fatigue. Actually, climbing stairs, known as a “gymnastic exercise”, is often recommended by the medical profession as a preventative medicine (Kroemer and Grandjean, 1997). At the same time it should be noted that exercise is not normally performed repetitively throughout an eight-hour period of the day. It is for repetitive shift work that energy expenditure calculations are utilized in the field of ergonomic design.

Fatigue related to climbing stairs and platforms, was measured using an energy expenditure calculation of walking up a 45 degree or 50% grade (Garg, et al. 1978). This work element combined with standing, which is assumed to be inherent within the cycle, was utilized to determine the exact amount of kilocalories burned per minute by an operator and repeated throughout the entire workday. The following factors were utilized in the calculation (See Appendix E):

**Body weight:** 196 lbs (88kg) to represent the 75th percentile male according to Konz, 1995.

**Velocity:** 3.2 ft / second (1 m / sec) and or one step per second

**Grade of floor:** 50%

**Load carried:** 0 lbs

**Distance carried:** 2 meters (7 ft) and or 2 steps

**Standing energy cost:** 2.1 kcal/min

It was found through this calculation that an operator will expend 2.68 kcal/min if
required to climb up two steps, up a 7 ft ramp or into a vehicle once per minute. This energy expenditure rate is independent of any other elements other than standing throughout the work cycle, which may be involved with a regular standard work assignment. However, the energy cost for climbing and standing alone has reached the moderate level of energy cost according to Eastman Kodak (1986). Also, the energy expenditure of 2.68 kcal/min related to this line item is greater than 70% of the recommended action limit of 3.5 kcal/min (NIOSH, 1991). It is very possible that only a few other physical elements will be required to obtain a high level of energy expenditure, when added to the climbing element described above. Thus, it is recommended that a checklist user highlight this item, even though the climbing element in itself is not an unacceptable practice. It is merely the goal of this line item to raise the red flag for potential fatigue related to high energy cost if the climbing greatly exceeds this value or if other heavy work elements are combined with this task.

2.4.3 Horizontal cumulative carry distance of greater than 20 ft per minute

This line item was developed to accommodate the fatigue felt by operators required to carry materials on every job cycle. Fatigue is often one ergonomic risk factor that is very hard to visually identify, but one that operators very often complain about. Whether it is fatigue induced by limited rest time, heavy loads or high walk distances, all can lead to cumulative trauma disorders. Therefore, a large component of the work rest ratio and energy expenditure calculations is time. For instance a pick and pack operator may carry heavy boxes for greater than fifty feet per carry without a problem, due to the fact that the amount of rest time or time spent not carrying throughout the day is more than adequate for this operator. However, operators that are required to carry objects one
or more times per minute, have a much lower tolerance for high walk distances. For the purpose of this line item, the term carry refers to walking while holding at least a 20 lb weight. Carrying and walking directly affect the operator's ability to complete assigned tasks during the cycle time. It is assumed that an operator can carry an object at the standard walk time of \(1\text{m} / \text{second}\). Carrying more than 20 ft (6.09m) increases the transportation time to more than 17% of the total cycle time (based on 78 cycles per hour).

An ergonomist can measure fatigue through an in-depth energy expenditure analysis, designed to determine the exact amount of kilocalories burned per minute by an operator throughout the entire workday. This analysis takes into consideration every work element completed by the operator. The University of Michigan's Energy Expenditure Model acknowledges that the carrying of loads greater than ten pounds at this distance can lead to a high, energy expenditure and ultimately fatigue. Twenty feet was highlighted from this software as the fine line between a low to moderate expenditure rating, through a statistical sample of thirty different hypothetical situations. To verify this finding, an energy expenditure calculation was completed using the Garg, et al. (1978), equation for carrying. The following factors were utilized in the calculation (See APPENDIX E):

**Body weight:** 196 lbs (88kg) to represent the 75th percentile male according to Konz (1995).

**Velocity:** 3.2 ft / second (1 m / sec)

**Grade of floor:** 0%

**Load carried:** 20 lbs

**Distance carried:** 20 ft
Standing energy cost: 2.1 kcal/min

It was found that an operator will expend 2.53 kcal/min if they are required to carry an object weighing at least 20 lbs for a cumulative distance of 20 ft, per minute. This energy expenditure rate is absent of any other elements except standing throughout the work cycle, which may be involved with a regular standard work assignment. However, the energy cost for carrying and standing alone has reached the moderate level of energy cost according to Eastman Kodak (1986). Also, the energy expenditure of 2.53 kcal/min related to this line item is greater than 70% of the recommended action limit of 3.5 kcal/min (NIOSH, 1991). It is very possible that only a few other physical elements will be required to obtain a high level of energy expenditure, when added to the carry element described above. Thus, it is recommended that a checklist user highlight this item and provide a risk value score of two when an operator is required to carry 20 lbs across a distance of 20 ft or more, at a repetition rate of one per minute.

2.4.4 Repetitive exposure to direct contact pressure or mechanical stress

Direct pressure and mechanical stress can cause musculoskeletal injuries through a variety of etiologies, while working on seemingly normal assembly operations. From visible contact stress marks or bruises on the skin, to complicated neuropathies caused by compressed nerves or muscular inflammation. For the purpose of this checklist, direct contact pressure and mechanical stress can be defined as any pressure, absorbed by the human body, that is either directly or indirectly related to the completion of a work element through the application of force. For example, using the hand as a hammer to seat trim panels or other clip in parts is a method of direct contact pressure. Another involves using the palm of the hand to roll rubber weather-stripping onto the metal flange
of a vehicle door or window opening. This type of direct pressure to the median nerve can lead to the common nerve compression disorder of the hand, carpal tunnel syndrome (Silverstein, 1987a). Leaning on the outside of a vehicle frame (metal) with the upper thighs to reach certain parts on the inside of an engine compartment or vehicle is another method of indirect mechanical stress. Also, carrying heavy loads across the forearms, can lead to lesions of the radial nerve. This condition has been previously recorded as a common neuropathy for bricklayers carrying stones on their forearms or in foresters carrying logs, as described by Spaans (1970). These forces can be applied in either a static or dynamic nature.

Due to the fact that there are many different situations or variables that can be identified as contact pressure or mechanical stress, no one repetition rate is being employed for this line item. The different variables that may be involved with this line item are the potential modes of pressure or force, the area of the body or specific joint affected, the type of force and speed of impact applied and the duration of time that the stress is applied throughout the work cycle. This checklist item should be merely referred to as a trigger to highlight risk to an ergonomist for further analysis. And the score of 2 for this yes or no answer should be added into the cumulative total for ergonomic risk for the entire operation.

One of the most common body regions, affected by direct pressure or mechanical stress for many manufacturing operations, is the palm of the hand. As stated in research by Feldman, et al. (1983), palmar neuropathy is an entrapment of the palmar branch of the ulnar nerve that innervates the hand through a shallow opening between the pisiform and hook of the hamate bones in the wrist. This direct contact pressure can result in nerve
weakness of the intrinsic muscles of the hand without loss of sensation. When repetitive forces are applied to the base of the hypothenar eminence over a period of time, damage to the palmar nerve can develop. (Feldman, et al. 1983). Sometimes the utilization of a pistol grip power requires a high initial feed force, that creates stress on the palm of the hand, through it’s interface with the gun handle. It is sometimes possible to cushion or absorb the mechanical stress through certain ergonomic aids or even personal protective equipment such as impact gloves, sorbathane hammers, thigh pads, automatic pressurizing fixtures and pre drilled holes for all fasteners.

2.4.5 Working with elbows over shoulder level for greater than 50% of the cycle

Working with hands overhead is a major risk factor associated with a large variety of neck, back and upper extremity disorders. The seriousness of this line item is caused by excessive postural constraints of the head and neck. When detected, this risk factor must be rectified immediately by reducing the exposure or by having an ergonomist consult on the actual work parameters, using a static postural analysis system.

In a very general sense, it has been commented that the hands and elbows should be well below shoulder level when performing a task to avoid potential operator to fatigue by causing micro-damage to muscle tissue. This damage, over time, causes Workplace Musculoskeletal Disorders (Dul and Weerdmeester, 1993). Using a variety of postures will ensure motion and avoid sustained muscle force. Sustained muscle force will lead to fatigue and reduced work capacity.

More specifically a raised arm posture, greater than 45 degrees in any direction, should be avoided (Hagberg and Wegman, 1987). Since the shoulder girdle is an extremely complex joint with multiple muscle systems affecting movement and stability,
a sustained raised arm posture may result in fatigue, discomfort or pain (Pheasant, 1991). Raising the arm away from the body engages the ligaments and small muscles surrounding the shoulder causing pain and discomfort to those tissues if the posture is prolonged or repeated (Dul and Weerdmeester, 1993 and Pheasant, 1991).

Wiker, et al. (1989) reported that movement performance was degraded immediately when the hands were placed overhead, regardless of the arm's postural direction (flexed or abducted). It was found by Wiker, et al. (1989a) the as the hands increase in elevation above shoulder level, both move and positioning sub-movement performance was degraded. Thus, above shoulder work can lead to poor quality with worker performance as well. The findings of this study show that working with elbows over shoulder level in either plane (coronal or sagittal) is definitely decreases speed-accuracy movement capability in humans performing manual assembly operations. Wiker, et al. (1989a), found that when the elbows were held over shoulder level, with hand loads similar to light hand tools or part assemblies, movement performance was degraded to more than 20%. This information is very applicable for this checklist due to the fact that the duty cycles used were comparable to those found in assembly operations (e.g., working between 20 and 40 s of a 60-s cycle). Wiker, et al. (1989b) found that tremor increased markedly following movement trials where the hands were placed above shoulder level.

Rotator cuff tendonitis may be a result of static tension in the tendon, occurring when the upper arm is abducted for a prolonged period of time (Hagberg and Wegman, 1987). Also, working with the arms overhead or elbows over shoulder level causes the pectoralis minor muscle or the scalene muscles of the neck to pinch those nerves and vessels that
pass underneath them (Wiker, et al. 1989b). Therefore, the decrements in movement performance and prevalence of workplace musculoskeletal disorders found in these studies help justify the line item (O 4) in the checklist that is aimed at confining sustained manual activity to below shoulder level.

2.4.6 Squatting, kneeling or crouching for greater than 50% of the cycle

With the increased awareness of ergonomics and the importance of neutral postures being stressed in job design, it may one day be possible that no operator should ever have to squat, kneel or crouch as part of their everyday job performance. However, there are still many cases in current day manufacturing where any of these three postures may indeed be inevitable. In fact, situations where operators are required to crawl into spaces, such as the inside of a partially built vehicle in automotive assembly, may force them to kneel or squat to complete a certain element without the ability to stand upright. The risks associated with these postures can range from muscular fatigue to soreness and ultimately nerve damage if gone undetected. Feldman, et al. (1983) states that crouching, kneeling and or squatting is associated with peroneal palsy, which is caused by entrapment of the peroneal and or posterior tibial nerves at the knee. “Features of the peroneal neuropathy include ‘foot drop’ (weakness in eversion of the foot and dorsiflexion at the ankle) and sensory loss along the distal lateral aspect of the leg and dorsum of the foot to the base of the large toe” (Feldman, et al. 1983). If, in fact, this type of posture is undoubtedly required, then the duration of exposure must be reduced or interrupted throughout the work cycle. Feldman, et al. (1983), also report that occupations requiring these postures, such as miners and shoe salesmen, have been historically associated with peroneal palsy, or foot drop.
Work by Silverstein, et al. (1987) indicates that for repetitive postures and force at the wrist, the duration of exposure greater than 50% of the work cycle is considered to be "highly repetitive". It was found that high repetitiveness, combined with awkward postures of the hand created elevated risks for cumulative trauma disorders, with odds ratios of 2.8 and 5.5 respectively, in multiple regression analysis. Even though the line item of squatting or kneeling is related to totally different body parts, the 50% duration of exposure will be used as the defining variable for risk. Considering the fact that when workers are required to kneel, 89% of their body weight is on a small surface area that already has minimal fatty tissue (Konz, 1995). This type of force to the knee joint is a prime risk factor for bursitis of the knee. "One of our patients who developed a peroneal palsy was a catcher on a college baseball team" (Feldman, et al. 1983). The duration of greater than 50% work cycle exposure over an entire day for a 40-hour workweek is obviously higher than that of a baseball catcher. Therefore, it is safe to say that this 50% duration action limit, is not overly conservative based on the reports by Feldman, et al. (1983) and Spaans (1970). Many other factors, such as repetitive and direct contact stress can also exacerbate the prevalence of peroneal palsy with these work postures. However, for the distinct purpose of this simple screening tool, the 50% duration level for either of these three postures will be identified with a yes or no answer, attaining a risk factor value score of either 2 or 0, respectively.
Chapter III: METHODS AND PROCEDURES

3.1 Methodology

Ergonomic factors related to repetitive manufacturing operations are often identified on a basic level using a variety of forms and surveys that are available to the ergonomics practitioner. However, it is often difficult for one person to study every operation at a manufacturing facility for the increasingly popular “plant wide comparison” that is being conducted at numerous automotive manufacturing facilities in North America. Many automotive assembly operations within a major automotive manufacturing company have already been analyzed using a risk factor checklist referred to as ErgoMAP (Ergonomic Manufacturing Assessment Protocol). The ErgoMAP is a preliminary ergonomic assessment tool that is being used by a wide range of personnel and is rapidly receiving attention and increased credibility, corporate wide. In fact, it has been discussed that the checklist will be completed on every manufacturing operation in the company and the results will one-day be compared with each other to develop corporate wide ergonomic priorities.

Therefore, the validation of this checklist, based on the literature and research in the field of ergonomics, is only one important piece of the puzzle. Reliability of the preliminary ergonomic assessment tool is also an extremely important aspect to the future success and credibility of the ErgoMAP checklist. Reliability between users will be crucial when comparing checklist results, considering the fact that hundreds of engineers, Ergonomists and health and safety professionals with varying levels of ergonomic expertise and experience will eventually be utilizing the checklist throughout the company. Equally important to the reliability between surveyors, is the ability of each
individual to utilize the tool with the same results time after time. Both between and within user variability evaluations are important to determining the ultimate reliability of the checklist. Finally, the ergonomic guidelines or action limits within line items of the checklist should not only reflect previous research, but should also correlate with injury data accumulated at the automotive manufacturing facilities. The determination of whether the line items, highlighted by a professional checklist user, match the epidemiological data recorded for the same operation is a critical measure of checklist validity.

The following section will outline the methods and show how the validity and reliability of the ErgoMAP checklist will be determined.

3.1.1. Subject Training and Utilization of the ErgoMAP checklist

Prior to the analysis of any operation, the subjects (checklist user) participated in 24 hours of ergonomic training provided by the company, within the last two years. The three-day training (24-hour) covers the basic concepts of ergonomics in industry, as well as the background behind the design specifications utilized in the checklist. Each subject also received two hours of specific training on the proper utilization of the ErgoMAP checklist, immediately prior to their "test" workstation analysis. The specific two hour training class was delivered by the one staff member responsible for overseeing the completion of each workstation analysis and training each volunteer checklist user / subject.

The ErgoMAP checklist is a simple step-by-step survey process aimed at helping the checklist user identify potential ergonomic risk factors from visually inspecting a workstation. During the final training class the participants received a manual called "The
User Friendly Guide to the ErgoMAP Checklist. The subjects were instructed and allowed to utilize the manual as required throughout any of their analyses. Another important document that was available at each workstation was the standard work instruction (SWI). This work instruction provided valuable bits of information needed to fill out the checklist. The operation identification information at the top of the checklist was filled out by directly referring to the SWI. The facility location, division, zone, column location, station number and cycle time are all available pieces of data from the SWI. The surveyors were required to fill out each one of the blanks at the top of the checklist for easy reference and comparison. The supervisor and date completed are two other pieces of information in the header of the checklist that were determined at the specific time of each analysis.

Repetition rate is a very important part of the checklist as it is the scoring system, with which each line item, section and total risk factor score of the tool is based. The initial step to determining the correct repetition value is to choose which cycle time category the operation falls within. This can be completed by referring to the SWI. If the exact cycle time is not published in the SWI, it was provided to the checklist user by the supervisor or industrial engineer assigned to the operation. Once the correct cycle time was chosen, one of the four repetition values was to be assigned to each line item on the checklist. A workstation cycle time has an obvious start and stop point for each of the subjects to visualize and refer to. Depending on the cycle time, each repetition value scoring system is explained on the checklist in detail (See Table 2) and must be applied to the 18 of the 24 specific line items according to the number of times the guideline is exceeded within one cycle.
Table 2: Repetition Value (RV): The RV applied to each line item is dependent on the number of repetitions per cycle.

<table>
<thead>
<tr>
<th>Category</th>
<th>RV Applied</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Cycle Time &gt; 1 min, &lt; 2 min</td>
<td>0. Never / not daily 1. Occasional or 1x / cycle 2. 2x / cycle 3. &gt; 2x / cycle</td>
</tr>
<tr>
<td>B. Cycle Time &gt; 30 sec, ≥ 1 min</td>
<td>0. Never / not daily 1. Occasional or &lt; 1x / cycle 2. 1x / cycle 3. &gt; 1x / cycle</td>
</tr>
<tr>
<td>C. Cycle Time &lt; 30 sec</td>
<td>0. Never / not daily 1. Occasional or &lt; 1x / cycle 3. 1x / cycle 4. &gt; 1x / cycle</td>
</tr>
</tbody>
</table>

After determining the appropriate cycle time, each checklist item was read by the user and compared to the operation being reviewed. For the between and within user study, cycle time A (> 1 min, < 2 min) was the repetition rating system utilized on all six operations. The checklist users were trained to review two line items per cycle, as there is sufficient time to accurately determine the repetition value that way. The subjects were also told to review the operation as a whole for a total of two to three complete cycles. This typically allowed a trained user to immediately eliminate approximately five line items that are not preformed throughout the workstation. By following the time related instruction below for the review of each line item, the checklist took an average of approximately 20 minutes to complete. The subjects were not required to fill out the element or comment section, but some did voluntarily if there they had time left at the end of the 20-minute period.

The subjects were instructed to review the SWI prior to watching the operations to take into consideration that the ergonomic design of the workstation is set up to accommodate a large percentage of the working population, excluding only the extremes. The trained subjects had an understanding of anthropometrics and were asked to review the workstation parameters and physical requirements of the operation based on a male, female mix of operator stature and weight between the 5th and 95th percentile of the population. Therefore, awkward postures required for operators who are visibly outside of this large population range were considered but not included directly into the checklist.
This was an important point that was stressed in the training session to each of the subjects, due to the fact that operators were not chosen for, or controlled within, any of the three experiments.

The “force” category consists of nine line items with force related guidelines involved. Object and tool weights were given to each checklist user verbally by the observer for each operation. This sped up the process by eliminating the need to use a scale. By providing the object weight to the subjects, we assumed that each trained user would be able to accurately weigh parts on a standard scale. The line items that require a push, pull or pinch grip force to be recorded were based on the user’s best visual judgement, and their review of the force related examples published in the user manual. Since normal checklist users are not expected to complete force gauge measurements for these line items outside of the study, the subjects were not asked to do so either. The power tool torque ratings were available on the SWI for the subject to refer to. Thus, with the information above provided and observed by the checklist user, they were required to apply a repetition value from the table above to each line item.

The “posture” category also consists of nine line items related to the postural guidelines found in the ergonomic research. One of the line items required a measurement of the horizontal distances reached. For this line item’s specific criteria, a standard 12-ft measuring tape was provided to the checklist user, in order to record the distance in inches. The remainder of the line items had a repetition value applied from Table 1, based on the postures witnessed by the observer for the body parts and joints in question. The final six risk factors in the “other” category were answered with yes or no and were given a score of 2 for all line items with a positive yes answer. The only thing
left for the subject to fill out was their name at the bottom of the checklist. The sub-total in each section and the total repetition value or risk factor score were added up and recorded by the staff member. The overall assessment of severity provided at the bottom of the checklist was not filled out, nor was considered a factor in the data analysis. The above procedure of checklist completion is related to the between subject and within subject experiments that are detailed below.

3.1.1.2. Subject Testing for the Proper Utilisation of the ErgoMAP Checklist

In order to ensure that the checklist users were properly trained and had an equal amount of ErgoMAP knowledge, they were tested using a common operation. The operation was the same one for every subject and the checklist was to be completed with no help from the instructor. To pass the test, the subject’s score had to be within an overall score of 2 (+ or −) from the instructor’s professional (template) score on that job. If their score was greater than 2 points away from the template, they would have received further instruction on some of their weaker points and be shown a video of another operation and asked to complete another “test” checklist. After that, if the subject did not pass they would have been required to complete the remainder of the jobs on the line, but their data would have been excluded from the study.

As shown in table 3, there was no need to exclude any of the subjects from the study as all test checklist scores were within a total value of two from the master template score. The volunteers who completed the testing were the same subjects for both the between user and within user evaluations.
Table 3: ErgoMAP results from the test condition, completed on the trim panel screw install operation and the St. Louis Truck Facility

<table>
<thead>
<tr>
<th>Risk Factor Codes</th>
<th>F1</th>
<th>F2</th>
<th>F3</th>
<th>F4</th>
<th>F5</th>
<th>F6</th>
<th>F7</th>
<th>F8</th>
<th>F9</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
<th>P6</th>
<th>P7</th>
<th>P8</th>
<th>P9</th>
<th>O1</th>
<th>O2</th>
<th>O3</th>
<th>O4</th>
<th>O5</th>
<th>O6</th>
<th>Total</th>
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<td>6</td>
<td></td>
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<td>6</td>
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</table>

3.1.1.3 Operation Selection

The six operations selected for the between and within user evaluations represent a wide variety of worker interface characteristics and elements. The operations were chosen through four different departments and six different zones throughout the plant, to establish the versatility of the ErgoMAP checklist. Some operations required forceful exertions, while others entailed primarily over-shoulder work, and still others jobs were lighter with a wide range of motion about certain joints. The operations are as follows:

1) Hang Door Channels: This operation is on the door line, where a hanging door moves by the operator while they reach into the sheet metal openings to install the channel. Fine finger movements, pinch grips and wrist deviations are all involved with this operation.

2) Rap Joint Molding: Operator works on the outside trim of the vehicle for most of the cycle, but is required to twist and reach into the truck for some work elements.

3) Plenum Pad Install: Underbody conveyor operation where over 50% of the work content is overhead. Upper extremity and neck postures are the focus of this operation.

4) Muffler Install: This operation is completed on the chassis frame line prior to being decked to the truck. The 24lb muffler is lifted and carried by the operator on every cycle.

5) Front Bumper Set: The utilisation of a large lift assist device with multiple nutrunners is part of this operation. Upper arm postures and push/pull force will be reviewed here.
6) Resonator Install: For this operation the operator is required to bend and work in the engine compartment of the truck while riding on a flat top conveyor, with the vehicle.

3.2 Between User Reliability

3.2.1 Subjects

Six subjects, who were previously trained for two hours on the proper utilization of the ErgoMAP checklist and successfully passed the test checklist evaluation, were utilized for the study. In addition, these individuals had been through the standard three-day ergonomic basics, training course offered by the company within the last two years. The checklist users were experienced in how to review manufacturing operations, as either safety representatives or engineers. These groups of individuals are the target checklist users for the future utilization of this preliminary assessment tool. Each subject had an opportunity to ask questions regarding the utilization of the ErgoMAP checklist, and sign a consent form indicating their understanding of how to review the 24 line items and apply risk factor scores based on the repetition value scale. The subjects for this testing were management and UAW volunteers from a truck assembly plant in St. Louis, Missouri.

3.2.2 Data Collection

Each subject was accompanied to six operations by the experimenter and left alone for twenty minutes at each workstation. The cycle times at the truck plant are 96 seconds in length. This means that the operator will start and finish a cycle of repetitive work within 96 seconds. The subjects were instructed to review two line items per cycle. They were also encouraged to skip over or eliminate any line items that are not applicable to the workstation being reviewed at the start of the twenty-minute time period. The two-
hour checklist completion time for 6 operations was conducted immediately after the
two-hour training session.

The data acquisition may have occurred with different operators being reviewed
on the same job, by the six different subjects. This variable of different operators was not
controlled, due to the fact that actual checklist completion in the field must be done this
way. The operator's studied at each of the six jobs were specifically instructed to
complete their operations using a normal pace and method. The checklists were given to
the experimenter immediately upon completion.

The subjects had 20 minutes to collect data and complete the repetition value
portion of the ErgoMAP checklist for all 24 line items, at each of the six workstations.
The data was collected on a new ErgoMAP sheet for each operation analyzed with the
appropriate header information filled out for the subject. This header information was
previously completed so that the subjects could better utilize the twenty-minute time
period to focus on the workstation analysis. The subject utilized the workstation
information provided in the SWI to obtain information such as tool weights, torque
specification for tooling, cycle times in minutes and the order of work elements included
with the cycle time. The remainder of the information was collected through observation
of the work being performed by the operator assigned to the workstation at the time of
ErgoMAP completion.

3.2.3 Data Analysis

3.2.3.1 Data Reduction

Each of the twenty-four checklist line items had a score recorded as well as the
cumulative total score. Each line item score within the force, posture, other categories,
along with the total risk value scores for each checklist was utilized as the dependant variable measurements for the study.

3.2.3.2 Statistics

The independent variable for this study is the 6 subjects that completed the ErgoMAP checklist on each of the 6 different operations. The score for each line item within force, posture and other risk factor categories are separate dependant variables, with the one related dependant variable measurement being the total score for each checklist. This is a repeated measures study, due to the fact that the same subjects are making every observation, across the 6 operations.

Next, a coefficient of variance, between each of the subjects was calculated for the total risk factor scores across all six operations. Also, a consensus count and total mean consensus between the six subjects was recorded and analyzed for each of the six operations. The consensus count was taken by giving a score of 1 every to each line item, every-time a risk factor was identified, regardless of the repetition value. So each line would have a score of 1 (risk) or zero (no risk) for each of the six subjects, on every line item. The total count (max = 6) or number of 1's given for each line item was then divided by 6 to get a percentage of subjects who did or did not identify a risk. The total count was then subtracted from six and divided by six, to determine the percentage of subjects not identifying risk for each line item. The higher of the two percentages, was then taken as the percent consensus for each line item across the six subjects. The percentage was then reduced by 50 and multiplied by 2, to get a total percent consensus of 0%, 33.3%, 67% or 100% for each specific line item. A total mean percent consensus for each of the six operations, was taken across the six subjects and 24 line items by
dividing the summed mean percent consensus from the 24 line items, by 24. The following are the percent consenses possible after the formula was used:

3 out of 6 identified a risk = 0% consensus  
2 or 4 out of 6 identified a risk = 33.3%  
1 or 5 out of 6 identified a risk = 67%  
0 or 6 out of 6 identified a risk = 100%

Mean values of the total checklist score had their own separate analysis of variance (ANOVA) run across the scores recorded for the 6 operations. To determine reliability between users, an interclass correlation (Pearson ‘r’) value was calculated to determine the correlation between the subject’s, based on the total risk factor scores for the six operations. The method uses the ANOVA table to obtain the reliability coefficient by subtracting the mean square of error from the mean square of subjects, and dividing by the mean square of the subjects.

3.3 Within User Reliability

3.3.1 Subjects

The same six subjects from a truck assembly facility in St. Louis, Missouri, utilized in the between user portion of the study, were used for the within user portion of the study. Each of the six subjects received the specific two-hour ErgoMAP checklist training from the experimenter and passed the test evaluation, prior to the first workstation evaluations. The criteria for choosing the subjects, their previous experience in observing manufacturing operations and the ergonomic training they received is identical to the between user study.

3.3.2 Data Collection

The subjects were asked to complete the ErgoMAP checklist on six operations within one day, for four separate days. The six checklists were completed four times and
had no less than five and no more than fourteen days between each. The six operations were chosen from the truck assembly facility, based on a commitment from upper management that those specific operations would not change throughout the potential eight-week period. Thereby, controlling the fact that all required work elements will be identical for the six subjects across the four-week period. The only thing that might have changed during the data acquisition period was the operator performing the operations. However, each operator was specifically instructed to complete their operation at their normal pace and method for every checklist conducted. The entire data acquisition time was approximately 10 hours, for each of the six subjects.

The six subjects were instructed to collect data in the identical fashion explained in the between user study. The checklists were given to the observer immediately upon completion. A clean checklist was utilized for each of the six operations across the four-trial repetitive measures. The subjects were not able to review or refer to the previous trial’s results on any of the operations, prior to completing the new checklists.

3.3.3 Data Analysis

3.3.3.1 Data Reduction

The scores from each of the twenty-four line items, as well as the total checklist score were collected as the dependent measures of the analysis. Therefore, there was an individual and total risk factor score for each of the 144 checklists completed.

3.3.3.2 Statistics

There were two independent variables for this study: 1) the six subjects who completed the checklist and provided the risk factors scores, 2) the four trials upon which the repeated measures will take place. The dependent measures were the individual and
total risk factor scores from the twenty-four line item checklists. Mean values of the total checklist score had their own separate analysis of variance (ANOVA) run across the scores recorded for the 6 operations. To determine reliability between users, an intraclass correlation coefficient was calculated, using the ANOVA table, as completed and described in the between-user section of this methods section. Next, a coefficient of variation was calculated between each of the four trials analyzed, for each subject, across all six operations. A consensus count was taken within each user, across the four trials, by providing a score of 1 when a risk was identified or zero when a risk was not identified, for each line item on all six operations. The total consensus score for each line item (max = 4) was then divided by 4 to get a percentage of trials that a risk was identified on. The total count was then subtracted from 4 and divided by 4, to determine the percentage of time across the four trials that each subject did not identify risk for each line item. The higher of the two percentages, was then taken as the percent consensus for each line item across four trials. The recording and calculation method of developing a percent consensus for each line item was the same as that described for the between-user evaluation. A total mean percent consensus for each of the six operations, was taken across the four trials and six subjects.

3.4 Epidemiological Study

Forty “core process” operations throughout a St. Louis minivan manufacturing facility were randomly chosen to be part of a study of validity, comparing historical injury statistics with ErgoMAP checklist scores.
3.4.1 Data Collection

The experimenter completed an ErgoMAP analysis on forty "core process" operations throughout a St. Louis minivan manufacturing facility. The experimenter is extremely practiced at the utilization of the checklist and has used the checklist on a daily basis for the past six years. Injury statistics from a St. Louis minivan assembly plant OSHA logbook were collected for forty operations. The experimenter completed an ErgoMAP checklist on the same forty operations to compare the scores with the injury statistics. The OSHA statistics were derived from the time period of 01/01/1998 to 12/31/2000. The operations were chosen from any division in the plant, after it was determined that they met the following criteria:

1. Injury data available from 01/01/1998 to 12/31/2000

2. No major operation change occurred within the process or workstation design across the three-year period. This was validated through an extensive review of the corporate standard work instruction database and discussion with industrial engineering.

After the forty operations without a major change were identified, the determination of incidence of injury took place by manually going through three years of OSHA log books and summary sheets. If an operation within the list of forty had one or more OSHA incidence recorded, the experimenter then opened each specific case to determine the number of lost work days (LWD) and/or restricted work days (RWD) associated with the case, if any existed. If no OSHA incidence were found for an operation, those operations were grouped into the "zero" category for incidence of injury, thus obtaining a score of zero for both the LWD and RWD categories. If an injury occurred and LWD's or RWD's
were found within a specific case, the number of days for each were normalized based on
the number of hours worked within the three year period.

3.4.2 Data Analysis

The dependant variables for this study were the number of incidences recorded,
the restricted work day rate, the lost time day incidence rate and the total ergonomic risk
factor score from the ErgoMAP checklist recorded on each of forty operations. The
incidence number is a raw number taken directly from the OSHA logs. The restricted
workday rate and lost time day incidence rate were found through normalizing the data
with the number of man-hours worked across the three-year period. Each of the forty
operations was ranked in order for all four, dependant measures.

3.4.2.1 Statistics

It was assumed that the number of cumulative trauma incidence per operation
studied would range from 0 to 6 for the three-year period. First, average ErgoMAP risk
factor scores were calculated for jobs having 1) zero injuries and 2) one or more injuries.
Next, the operations were also binned into three different categories based on the
ErgoMAP scores. The bin size using an ErgoMAP value of 5 was chosen to represent a
simple and clear separation that may be used in the field to depict high, medium and low
risk operations. The actual values identified for each bin were 0 - 4.9 (low), 5 - 9.9
(medium) and 10+ (high). The mean incidence number, restricted work day rate and lost
work day rate will be compared to the ErgoMAP scores across the three bins.
Chapter IV: RESULTS

The results have been divided into three sections: 1) The Between-user Reliability Evaluation, 2) The Within-user Reliability Evaluation and 3) The Epidemiological Data vs. ErgoMAP Checklist Evaluation.

4.1 Between-user Reliability

For this experiment, six subjects were used to determine the between user reliability of the tool. Each had the same training, but varying degrees of experience with the ErgoMAP checklist. It was determined that the first trial data recorded by subject #2, was an out-lier and was, thereby, replaced with the data from that subject's second trial.

4.1.1 Consensus Data

A consensus count was taken across the six subjects, for every line item studied on each of the six operations, by determining the consistency of checklist entries for each line item. This count was taken regardless of the repetition rate recorded. A mean percent consensus was recorded across the six subjects for each of the six operations, which ranged from 72.2% to 87.5% consensus (Figure 1). The overall mean consensus was 80.5%.

Also, a mean percent consensus was recorded across the six operations for each line item to determine which line items resulted in the least consensus among the subjects. The means for each risk factor ranged from 33% to 100% consensus across twenty-four line items (Figure 2).
Figure 1: Mean percent consensus for each of the six operations, across the six subjects and 24 line items. Standard deviations are indicated. (N=24)

Figure 2: Mean percent consensus across the six subjects for each risk factor category, across the six operations. Standard deviations are indicated. (N=6)
4.1.2. Between-user Differences for Total ErgoMAP Scores

To compare the total risk factor scores between users, the mean score from each operation was averaged across the six subjects. The mean value across subjects for the six operations' ranged from 5 to 11 (Figure 3).

![Bar graph showing mean ErgoMAP scores for different jobs.](image)

**Figure 3**: Mean risk factor score between subjects for each of the six operations studied. The bars indicate the standard deviation between users. ($N=6$)

Coefficient of variation values, between-users, were calculated with the Total ErgoMAP Score means and standard deviations for each job. The overall mean coefficient of variation across the six operations was 36.1%, between the subjects. The operation with the highest and lowest coefficient of variation, were the Front Door Channels (67%) and Resonator Install (18%), respectively (Figure 4).
Figure 4. Coefficient of variation for the Total ErgoMAP Scores between subjects. The overall mean coefficient of variation across the six operations is also indicated. (N = 6)
Figure 5. Mean Total ErgoMAP Scores between-users, across the six operations. The overall mean Total ErgoMAP Score is also indicated in this figure.

The data were also compared between-users, by reviewing the overall means of each subject, across the six operations reviewed (Figure 5). It is important to note that subject # 6 is considered to be the "expert" or gold standard for the evaluation of the ErgoMAP checklist, among the six subjects. It is also apparent in figure 5 that subject #1 had the highest mean Total ErgoMAP Score, across the six operations.

4.1.4 ANOVA Between-user Data

An interclass correlation formula was utilized to compute correlation between-users, based on their total risk factor scores for the six operations. The approach uses ANOVA to obtain the inter-rater correlation or reliability coefficient, between-users. The interclass correlation was $r=0.832$ (Figure 6).

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<tr>
<th></th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F-Value</th>
<th>P-Value</th>
<th>Lambda</th>
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<td>4.311</td>
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</tr>
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</table>

Figure 6. ANOVA table for the between user reliability measure.

4.2 Within-user Reliability

4.2.1 Consensus Data

A mean percent consensus, between observation days, was recorded for the 24 line items across the six subjects for each of the six operations, which ranged from 76% to 100% consensus (Figure 7). The overall, mean consensus within the subjects and across the six operations was 92.3%.
Figure 7: Mean percent consensus within all subjects, across four trials (N=24). The percent consensus does not take into consideration the repetition rate recorded, merely the presence of the risk factor itself.

4.2.2. Mean Comparison Information

Within user coefficient of variation values, were calculated utilizing the Total ErgoMAP Score means and standard deviations for each job. As found in the between-user study, the operations with the highest and lowest coefficient of variation were the Front Door Channels (41%) and Resonator Install (14%), respectively (Figure 8). The overall mean coefficient of variation across the six operations was 24.9%, between the subjects’ four trial test period (Figure 8). This overall coefficient of variation, within-
users, across the four trials, for all six operations, was more than 10% less than that found across the six operations for the between-user study.

Figure 8: Average coefficient of variation within all six users, across the four trials. The overall, mean coefficient of variation across the six operations is also indicated. (n=24)
Figure 9: Coefficient of variation within subject’s total ErgoMAP scores across the four weeks, for each of the six operations studied. From these figures it becomes apparent that certain subjects have much higher within-user variability than others.
4.1.4 ANOVA Within-user Data

The intraclass correlation r-value, for the within-user study of total risk factor checklist scores across the six operations studied, was r=0.805 (Figure 10).

<table>
<thead>
<tr>
<th></th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F-Value</th>
<th>P-Value</th>
<th>Lambda</th>
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<td>41.95</td>
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<td></td>
<td></td>
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</tr>
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<td>Job</td>
<td>3</td>
<td>111.4</td>
<td>37.2</td>
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<td>773.8</td>
<td>7.4</td>
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</table>

Figure 10. ANOVA table for the within-user reliability measure.

4.3 Epidemiological Study

To document the face validity of each checklist line item, a review of literature was completed to support the guidelines utilized in the checklist with empirical data from the field of ergonomics. However, to determine the validity of the checklist as a tool to predict ergonomic risk within the prescribed manufacturing environment, a comparison was made between the historical injury statistics and the Total ErgoMAP score for forty operations.

4.3.1 ErgoMAP Analysis

The experimenter was extremely practiced at the utilization of the checklist. He completed an ErgoMAP analysis on forty “core process” operations throughout a St. Louis minivan manufacturing facility. The ErgoMAP scores across the forty operations ranged from 0 to 13, with the average (mean) score of 5.05.

4.3.3 ErgoMAP Analysis, Compared to the Injury Statistics

When the incidence of injuries over a three-year period, per operation, was pooled into two categories (0 injuries and 1+ injuries), it was found that there was a large difference
in the mean ErgoMAP scores between both categories. The Zero group had an average score of 2.3 and the 1+ group had an average score of 8.4 (Figure 11). The average ErgoMAP score for operations containing zero or 1+, injuries over the three-year period was 2.3 and 8.4 respectively. Thus, operations that resulted in a recorded injury had ErgoMAP scores that were an average of 3.7 times higher than those without an injury.

![Bar graph showing mean ErgoMAP score by number of incidences per operation](image)

Figure 11: The mean ErgoMAP score compared to operations with and without injuries (N=40).

The ErgoMAP score for each of the forty operations was also binned into one of three categories. The range of each category was chosen by the experimenter to represent an even
distribution of units, 5 per bin. This symmetrical bin size, was chosen to accommodate the "red, yellow, and green" risk factor category system that is utilized at the automotive manufacturing in question. Figure 12, indicates the average raw number of OSHA incidence within each Total ErgoMAP Score bin and shows an increase in number of incidence with an increase in score range. If an injury was present within the list of forty operations reviewed, then the number of restricted workdays and lost workdays were normalized based on the number of hours worked within a three-year period (Figure 13 & 14).

![Bar chart showing the mean number of OSHA incidence per operation, binned into three separate ErgoMAP score categories. (N=40)](image)

Figure 12: The mean number of OSHA incidence per operation, as binned into three separate ErgoMAP score categories. (N=40)
Figure 13: The mean number of RWD cases normalized per 100 hours worked per operation, as binned into three separate ErgoMAP score categories. (N=40)

Figure 14: The mean number of LWD cases normalized per 100 hours worked per operation, as binned into three separate ErgoMAP score categories. (N=40)
Chapter V: DISCUSSION

The current study was designed to determine the reliability and validity of the ErgoMAP risk factor checklist when compared between-users, within-users and against OSHA injury statistics related to ergonomic incidence. Few studies like this have been conducted previously to review both the validity and reliability of a preliminary ergonomic screening tool. As discussed in a study by Keyserling, Brouwer and Silverstein (1992) a control study, to review the between user variability on the same operations, was not possible due to a lack of resources. The ErgoMAP checklist itself was comprised of twenty-four line items that have guidelines derived from established research from the field, as described throughout the review of literature. One of the main findings of the study was that checklist users (subjects), with varying degrees of experience, were able to identify the existence of ergonomic risk on identical line items over 80% of the time. In fact, the mean percent consensus across all twenty-four line items on every operation studied was 81% and 92% for the between-user and within-user evaluations, respectively. Certain risk factor line items had a higher percent consensus than others, with values ranging from 33% to 100%. However, the overall ability of different checklist users to consistently identify the same line items was confirmed. Another finding from the epidemiological study was that, as ErgoMAP scores are binned into categories with increasing values, the operations that fall within those categories had a visible increase in related injury statistics. Thus, as the ErgoMAP scores increased for certain operations, so did the incidence of the ergonomic injuries, restricted workday rate and lost workday rate. The ErgoMAP score was found to be an average of 3.7 times higher for
operations with an ergonomic incident, than those operations with no incidence recorded over a three-year period, from 1998 to 2000.

5.1 Between-user Reliability

It was hypothesized that subjects would consistently identify the existence of risk factors, regardless of the repetition rate related to the line item. It was found that the average consensus between users was 80.5%. It was also found that subjects were most proficient at identifying the occurrence of ergonomic risk within the Force (84% consensus) and Other (85.2%) risk factor categories. The subjects had the least consensus within the posture (70.4%) category. This reduced ability to identify the prevalence of an ergonomic risk factor in the posture category, may be due to the fact that several different operators were evaluated within the study. The line items in the posture category are much more dependant on the work technique of the operator, than those line items in the Force and Other category which are more strictly based on the design of the tasks and the tooling/equipment involved. This finding is consistent with a study by Keyserling, Brouwer and Silverstein (1992), where some workers were reassigned during the study period, which was said to “have contributed to poor correlation, mainly in the work-method-sensitive measures such as trunk and neck postures”. In previous research reviewing the utilization of a preliminary screening tool by Kilbom and Persson (1987) and Drury (1987), it was found that it is best to have the regular operator available for every checklist evaluation. This is due to the fact that variation in work technique between operators is such a powerful factor in analyzing operations (Kilbom and Persson, 1987). For the purpose of this study, it was not possible to control which operator
would be present during each of the six subject's utilization of the ErgoMAP and review of the operation.

From a review of the consensus data across the six users for each of the 24 line items, it is obvious that certain items have a larger variance from the mean, than others. There were only two items that had a less than 50% consensus recorded on them. Those were, as follows:
1. F9 - Pinch grip greater than 2 lbs, P7
2. P8 – Wrist ulnar deviation greater than 20° and radial deviation greater than 15°. Both of these line items have been considered to be important risk factors from the literature, but are very difficult to precisely determine from merely a visual perspective. For the most part, without the proper equipment, determining whether someone is required to perform a pinch grip greater than 2lbs, becomes an educated or experienced guess. Also, without a goniometer, the exact level of wrist deviation present is hard to see and may look different every time.

The mean between-user coefficient of variation for the Total ErgoMAP score was observed to be 36% (Figure 4). This can be looked upon as an acceptable coefficient of variation, considering the vast difference in experience level of the six subjects. There was a large difference in the coefficient of variation between users of 48.8% from Jobs #6 and #1. The variability went from 66.9% on Job #1, to 18.1% on Job #6. This large discrepancy may be explained by the much higher Total Risk Factor Scores that Subject #1 had compared to the other five subjects on every operation, except on Job #6. The mean Total Risk Factor Score for subject #6 was higher than the mean Total Risk Factor Score for each of the five other subjects across the six operations (Figure 5). In fact, Job #6, had the highest checklist score across the subjects, with a mean score of 12 between the six users (Figure 3). This
higher mean score for Job #6 (Resonator Install) is most indicative of the results attained by subject #1. Subject #1, may theoretically have recorded consistently higher scores in an effort to be extremely thorough. However, Job #6 was scored high by all subjects, so in comparison to the other operations, this one did not have many other risk factors in the checklist to identify that were not done so by the rest of the subjects.

The utilization of trial number one for the between-user study was done to control the amount of knowledge or practice that each subject had with the six operations. In the field, the screening tool will be utilized on a "one time" basis per operation, and scores between users will be typically compared in the plants, based on the first time review for each user. Therefore, a very minimal amount of pre-conception or recollection of the amount of ergonomic risk related to the jobs could have been involved with the subject's analysis.

A strong reliability measure of $r = 0.832$ was found utilizing an interclass correlation computation, for Between-user Total ErgoMAP Scores. This is consistent with the hypothesis that checklist users will reliably identify the same level of ergonomic risk between each other, when analyzing identical operations.

5.3 Within-user Reliability

A strong consensus was found within-users for the identification of ergonomic risk across every line item with an average of 92.3% and a range from 76% to 100%. This shows that ErgoMAP checklist has a very high reliability to identify the existence or non-existence of ergonomic risk factors, regardless of repetition.

As expected, the average within-user coefficient of variation (25%) for the within-user study was markedly lower than that found in the between-user study (36%). It was
predicted that scores for subjects who review the same jobs time after time would show less variability than when comparing scores between subjects, for a one time analysis. The increased amount of trials and experience involved in reviewing the same operations, four separate times in the within-user study, may have also contributed to the improved within-user coefficient of variation. However, there was a large difference shown in the coefficient of variation between subjects across the four trials (Figure 9 a - f). The within-user coefficient of variation ranged from 82% to 21% for subject number 4 and number 6, respectively (Figure 9). This large difference can be attributed to the level of experience with the preliminary ergonomic assessment tool. Subject #6 was considered the expert and co-developer of the checklist with over six years experience using it, while subject #4 had merely the ErgoMAP training and test trial to practice his skills.

In fact, experience played a big role in the coefficient of variation scores within subjects. The six subjects can be broken into two distinct groups to show the importance of experience and practice using the tool. The first group (A) of three individuals (#1, #4, #5) had very little practice using the ErgoMAP tool (less than 10 times in the past two years). However, they have had the specific two-hour training, as well as plenty of experience reviewing the results of ErgoMAP checklists completed by other individuals. The second group (B) of three individuals (#2, #3, #6) uses the ErgoMAP checklist between 3 – 5 days per week and has each completed over 500 assessments with the tool in the past two years. This explains the fact that group A (inexperienced) had a six times higher mean coefficient of variation than group B (experienced). Therefore, the mean variation scores were 43% for Group A and 7% for Group B, across the six operations, highlighting the influence of experience on consistency with-users.
A reliability measure of $r = 0.81$ was found, within-users, utilizing an intraclass correlation computation for Total ErgoMAP Scores. This high correlation leads us to accept the hypothesis that checklist users will reliably identify the same level of ergonomic risk within each other, when analyzing identical operations during separate trial periods.

5.4 Between-user and Within-user Reliability Limitations

There were certain limitations found after the examination of results that should be addressed with regards to these two sections of the study. First, conclusions must be made with the understanding that a different operator was viewed on numerous occasions on the same operations for both the within and between user study. It has been documented in the past that when the regular operator is not reviewed different operator technique plays an important role in the proper ergonomic assessment of an operation (Kilbom and Persson, 1987 and Drury, 1987). Operators with even slightly different anthropometrics can have vastly different work methods or techniques to accommodate for their size. Also, experience of the operator on the job can greatly affect the technique they utilized, due to a series of habits that may or may not be present. Without controlling the operator’s studied throughout the trials, and between subjects, the total checklist scores are likely to have greater variability than if the regular operator was witnessed on every operation for every subject on every trial.

The role, within the plant, of each of the subjects may also have driven the scores for each of the trials. One subject in particular (#4) was found to be more conservative than the other subjects for the between-user, one time evaluation. This subject happened to be the only UAW representative in the group of six, and their first trial data was considered to be an out-lie.
Finally, even though the subjects received the same ergonomic training before the study, it is impossible to determine that they each left the class with the same amount of retention or working knowledge of the basic ergonomic concepts and how to use the checklist itself. Thus, a third limitation of the between and within-user evaluations, was the experimenter’s ability to control the amount of ErgoMAP experience and knowledge that each subject brought to the study.

However, it should be noted that these limitations are everyday factors that the ErgoMAP checklist will be faced with and are therefore “real world” considerations that must be addressed when discussing future utilization of the tool across the company.

5.5 ErgoMAP Validity Based on Epidemiological Data

It was hypothesized that the occurrence of injuries as well as lost time and restricted work day rates would be higher on operations with higher ErgoMAP scores. The data lead to an acceptance of this hypothesis through an obvious results that ErgoMAP scores are higher on operations with an OSHA recordable incident (2.3), versus operations without an incident recorded (8.4). It should be noted that all of the epidemiological data utilized in the study was taken from a historical OSHA log, related to only cumulative trauma or other ergonomically related incidence. Also, the forty operations reviewed were chosen from a list of jobs that the corporate standard work instruction database proved to have no work element changes over the three-year period. The results from the database were verified through discussion with the industrial engineer responsible for development of work instructions for the specific operations involved with the study. However, there was no way to rule out the potential
effect that minor tooling, equipment or part presentation changes may have had on the outcome of OSHA incidence.

The ErgoMAP scores were pooled into three different categories with 5 units in each category, and were then compared to three separate epidemiological dependant variables. In every case, as the dependant measure of injury statistics increased with the elevation of Total ErgoMAP score, from one bin to the next. This finding is not unlike the results from a study by Kilbom and Persson (1987), where significant relationships were found between working technique data and upper extremity disorders. This finding reinforces the prioritization of risk across the three categories, and may lead the company to define operations as low, medium and high risk, based on the bin level, that the score resides in.

5.5.1 Limitations in the Determination of ErgoMAP Validity

One major limitation of this portion of the study is the fact that not all epidemiological data can be considered pure, especially when reviewing lost time, and or restricted workday cases. This is due to the fact that a high number of extraneous variables, with no relevance to the operation itself, can drive an extremely high number of lost time or restricted workdays. For example, an operator with a significant family event or crisis, occurring at the same time as the OSHA incident, may have psychosocial factors that increase the severity of the disorder or injury even though injury statistics were only utilized if they were categorized as ergonomically related, eliminating all laceration, contusion and non-repetitive type injuries. It was not possible to ensure whether or not preexisting injuries or symptoms attained from working on other operations, or from the outside, played a role in exacerbating the recorded incidence. For instance, an operator may work on one operation for 10 years, building up an assortment of cumulative trauma symptoms, but may one-day
switch to a new job and within a matter of weeks report an ergonomic injury. In this case, the OSHA incident will be recorded on, and attributed to, the latter of the two operations in question. There was no way for the researcher to exclude this potential confounding variable, from the OSHA reporting log that was investigated, without actually being present for the recording of each injury.

Another limitation is, not knowing the exact work method of any operator that was injured throughout the three-year period. Even though, the jobs were only chosen if the standard work instructions were proven to have no changes, there was still no way to ensure that the work method for all operators across the three year period was the same as the operator witnessed during the ErgoMAP analysis. As discussed in Kilborn and Persson (1987), even if the main tasks of the job remain unchanged, a worker can revert to bad habits or old techniques, especially if put under stress by other individuals in the working environment or time constraints.

Also, it was not feasible to determine whether there were any changes made to the tooling, equipment and part presentation, throughout the three-year period. All of which are key factors to the interaction of the operator with their work environment.

Finally, there is limitation of calculating the total ErgoMAP score, based on 18 line items (out of the 24) using “repetition”, as defined from very sparse data and research. The main findings utilized for the development of the ErgoMAP Repetition Value scoring system comes from the well known research done by Silverstein (1987). However, the lack of clinical and epidemiological data supporting the definition of what is “repetitive”, leads to some assumptions in the determination of risk level based on frequency.
Chapter VI: CONCLUSION

This study was designed to reveal the level reliability and validity of the ErgoMAP checklist and did, indeed, offer advances into the determination of both measures.

6.1 Hypotheses

It was hypothesized that different users of the ErgoMAP checklist will reliably identify ergonomic risk, when completing the analysis on the same operations. Findings from both the consensus data and interclass correlation conducted in the between-user study lead to the acceptance of this hypothesis. Results indicate a high overall mean consensus of 80.5% between users for the identification of ergonomic risk throughout all 24 line items on every operation reviewed. Secondly, the interclass correlation also indicated good reliability, with values of $r=0.83$ between-users.

It was hypothesized that any user of the ErgoMAP checklist will reliably identify ergonomic risk on the same operations over a course of four separate analysis trials. Consensus data was even stronger for subjects who participated in the within-user evaluation, with a mean percent consensus across the users of 92.3% for the identification of ergonomic risk throughout the twenty-four line item ErgoMAP. The overall mean coefficient of variation for the within-user analysis was less than 25% across the six subjects involved and the interclass correlation was $r=0.81$. These findings of high consensus and low variance through the utilization of the tool on multiple observations of the same task, leads to the acceptance of within-user reliability for the ErgoMAP checklist. Note, that these successful results were found in a study where it was possible to have different operators each time the job was reviewed.
It was hypothesized that the ErgoMAP checklist scores would be correlated to the historical epidemiological statistics recorded across forty manufacturing operations. This hypothesis can be accepted due to the overwhelming results that indicate an increase in injury statistics with an increase in Total ErgoMAP Scores, across forty operations.

6.2 Implications for the Automotive Company

Management now has the data necessary to proceed with a high level of confidence that the preliminary ergonomic screening tool, currently being utilized on numerous operations by different users, will indeed help predict where ergonomic risk is involved with a specific operator method. The one page checklist for evaluating ergonomic risk factors was developed to be utilized by persons who had obtained basic ergonomic training as well as moderate to strong analytical experience in the manufacturing environment. It appears that the experience required for reviewing jobs does not necessarily need to be ergonomically related, but understanding the work environment and having a working knowledge of operator performance is important. It was found that even with the wide range of experience and ergonomic knowledge between the six subjects, overall consensus of risk factor identification was extremely high. This finding will help re-assure the company that, regardless of the overall score or repetition rate identified, the identification of raw ergonomic risk will be quite reliable no matter who the trained user is or who they are evaluating.

Similar to the checklist utilized in a study by Keyserling, et al. (1992), the ErgoMAP was found to be an effective instrument for identifying potentially harmful exposures to ergonomic risk. This finding was validated through the comparison of mean Total ErgoMAP Scores which increased from 2.3, on jobs with no injuries, to 8.4 on jobs with at least one
recorded injury. If the tool is continually utilized by the automotive manufacturer throughout every facility, their next step will be to prioritize the level of risk identified on the checklist and bin the values into “red, yellow and green” categories. In fact, the linear results that were found in the epidemiological data, from the binning of Total ErgoMAP Scores into three groups, will help define and support the “red, yellow and green” indices to be utilized by the company.

Many “real world” factors were present and uncontrolled for throughout this study, yet strong reliability and validity results were prevalent. Factors such as a wide range of checklist user experience, the ability for different operators with varying techniques to be witnessed by different users and the defined in-plant role that a checklist user has, may all impact the reliability and validity of the ErgoMAP checklist. Therefore, the results from this study can be accepted by the company at face value, due to the fact that the tool’s validity and reliability were established in the absence of many artificial controls in the study.

It has been identified, through past practice with this tool, that it is most effective for the review of cyclic operations. Due to this fact, both the force and posture line items are given a value based on the repetition rate per cycle and not per shift. Operations that do not involve the same work repetitively would be much harder to assign ErgoMAP values to given the current checklist design. Therefore, a similar study using the ErgoMAP checklist on non-cyclic operations would most likely not be as encouraging as the current results.

6.3 Future Direction

The current study was performed to ensure that the current utilization of the checklist within a major automotive company is yielding the desired results of screening out major ergonomic factors, and ultimately predicting the potential risk of cumulative trauma injury.
Further ErgoMAP between user, within user and epidemiological studies should be completed on larger population of operations throughout the company, while at the same time using other popular preliminary screening tools from the field within the same study to compare reliability and validity results between tools. The comparison of the ErgoMAP checklist with other tools may also lead to a review of the additive nature of the ErgoMAP scoring system. Some popular ergonomic analysis tools, such as the Strain Index, weight certain risk factors more heavily than others and use a multiplication of factors.

Also, emphasis should be placed on a controlled study of exact operator method, using periodic operator training and subsequent analysis, throughout the historical data collection period. Information from such research may lead to a more accurate comparison between risk factor levels and the exact ergonomic injuries attained. Further ergonomic training modules and analysis technique classes should be developed by the company to help normalize the effect of checklist experience between users. A testing procedure should be enforced for all potential checklist users to help ensure some level of consistency. More in-depth training, on certain line items derived from the consensus data as more difficult to identify between users, may help with the checklist reliability. Also, from the finding that experience played such an influential role in CofV, a pre-ErgoMAP usage test period of over 100 operations may be enforced by the company to help improve the competency and consistency of ErgoMAP users.
REFERENCE


APPENDICES
# Appendix A

## Ergonomic Workstation Survey

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**Job:**

**Date:**

**Location:**

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<th>Yes</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Twisting clothes wringing motions of the wrist</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Working with bent wrist</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vibration tools</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Poor tool hand grip</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Repetitive hand, arm and shoulder movements</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Arms or elbows high or outstretched</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Controls or materials beyond easy reach</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Working with a bent neck</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Working with a bent spine or excessive leaning</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lifting a load from an improper height</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Excessive twisting or stretching of the back</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Excessive push pull on loads</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Excessive static standing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Working in an immobile position too long</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Improper heights of work surfaces</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other</td>
</tr>
</tbody>
</table>

**Methods Engineer:** ______________________

**Supervisor:** ______________________
Appendix B

ERGOMAP CHECKLIST
A PRELIMINARY ERGONOMICS ASSESSMENT TOOL

<table>
<thead>
<tr>
<th>Facility Location:</th>
<th>Zone / Area:</th>
<th>Actual Cycle Time:</th>
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</thead>
<tbody>
<tr>
<td>Division:</td>
<td>Column Location:</td>
<td>Supervisor:</td>
</tr>
<tr>
<td>Job Name:</td>
<td>Station Number:</td>
<td>Date Completed:</td>
</tr>
</tbody>
</table>

REPETITION VALUE (RV): The RV applied to each line item is dependent on amount of repetitions per cycle.

- A. Cycle Time > 1 min < 2 min: 0. Never / not daily 1. Occasional or 1x / cycle 2. 2x / cycle 3. >2x / cycle
- B. Cycle Time > 30 sec. ≤ 1 min: 0. Never / not daily 1. Occasional /not every cycle 2. 1x / cycle 3. > 1x / cycle
- C. Cycle Time ≤ 30 sec: 0. Never / not daily 1. Occasional /not every cycle 3. 1x / cycle 4. >1x / cycle

<table>
<thead>
<tr>
<th>Force:</th>
</tr>
</thead>
<tbody>
<tr>
<td># Risk Factor</td>
</tr>
<tr>
<td>F1 Two-handed lift greater than 20 lbs</td>
</tr>
<tr>
<td>F2 Two-handed carry greater than 30 lbs</td>
</tr>
<tr>
<td>F3 Two-handed horizontal push/pull (44 lbs initial/24 lbs sustained)</td>
</tr>
<tr>
<td>F4 Two-handed vertical push/pull greater than 25 lbs</td>
</tr>
<tr>
<td>F5 One handed horizontal push force greater than 15 lbs</td>
</tr>
<tr>
<td>F6 Use of hand/power tool greater than 5 lbs without balancer</td>
</tr>
<tr>
<td>F7 Trunk rotation with a weight greater than 10 lbs</td>
</tr>
<tr>
<td>F8 Power tool torque rating: right angle &gt;37 ft-lbs, pistol grip &gt;26 in-lbs</td>
</tr>
<tr>
<td>F9 Pinch grip of greater than 2 lbs (R or L)</td>
</tr>
</tbody>
</table>

FORCE RISK FACTOR TOTAL =

<table>
<thead>
<tr>
<th>Posture:</th>
</tr>
</thead>
<tbody>
<tr>
<td># Risk Factor</td>
</tr>
<tr>
<td>P1 Horizontal reach distance greater than 20&quot;</td>
</tr>
<tr>
<td>P2 Back flexion &gt; 45°</td>
</tr>
<tr>
<td>P3 Neck flexion &gt; 30° or extension &gt; 20°</td>
</tr>
<tr>
<td>P4 Trunk or neck side-bent and or flexed, plus twisted or rotated.</td>
</tr>
<tr>
<td>P5 Shoulder abduction greater than 90° (R or L)</td>
</tr>
<tr>
<td>P6 Working with hands or arms behind the body (R or L)</td>
</tr>
<tr>
<td>P7 Wrist flexion or extension or greater than 45° (R or L)</td>
</tr>
<tr>
<td>P8 Wrist deviation, ulnar &gt; 20° or radial &gt; 15° (R or L)</td>
</tr>
<tr>
<td>P9 Pronation or supination of hand against a resistance (R or L)</td>
</tr>
</tbody>
</table>

POSTURE RISK FACTOR TOTAL =

OTHER RISK FACTORS:

<table>
<thead>
<tr>
<th># Risk Factor</th>
<th>Yes</th>
<th>No</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>O1 Noticeably high tool or floor vibration</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O2 Climbing up 2 steps, a 7ft ramp, or into a vehicle once per minute</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O3 Horizontal cumulative carry distance of greater than 20 ft per minute</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O4 Repetitive exposure to direct contact pressure or mechanical stress</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O5 Work with elbows over shoulder level for greater than 50% of cycle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O6 Squatting, kneeling or crouching for greater than 50% of the cycle</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

OTHER RISK FACTOR TOTAL =

Sample Assessment Priority Legend:

- 0-2 Green: Operation within established criteria
- 3-11 Yellow: Opportunity for continuous improvement
- 12+ Red: Committee review item (LEPC) or Launch

TOTAL RV SCORE: [Computation]

COMPLETED BY: [PRINT NAME]

Overall Assessment: Green [Computation]
Yellow [Computation]
Red [Computation]

104
# Appendix C

## ERGONOMIC RISK FACTOR CHECKLIST

<table>
<thead>
<tr>
<th>#</th>
<th>Risk Factor</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>F 1</td>
<td>Two handed lift greater than 20lbs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F 2</td>
<td>Vertical travel distance of lift greater than 60&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F 3</td>
<td>Horizontal lifting reach greater than 20&quot; from body</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F 4</td>
<td>Two handed carry greater than 30lbs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F 5</td>
<td>Horizontal carry distance of greater than 20ft</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F 6</td>
<td>Two handed horizontal push/pull greater than 40lbs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F 7</td>
<td>Two handed vertical push/pull greater than 25lbs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F 8</td>
<td>Trunk rotation with a weight greater than 10lbs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F 9</td>
<td>Wrist rotation while manipulating greater than 6lbs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F 10</td>
<td>One hand horizontal palmer push greater than 15lbs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F 11</td>
<td>Use of hand tool greater than 7lbs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## POSTURE

<table>
<thead>
<tr>
<th>#</th>
<th>Risk Factor</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>P 1</td>
<td>Trunk forward flexion greater than 45°</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P 2</td>
<td>Trunk extension greater than 20°</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P 3</td>
<td>Neck flexion □ or extension □ greater than 45°</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P 4</td>
<td>Trunk □ or neck □ side-bent plus twisted</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P 5</td>
<td>Shoulder abduction greater than 90°</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P 6</td>
<td>Working with hands □ or arms □ behind body</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>P 7</td>
<td>Full elbow extension with shoulder elevation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P 8</td>
<td>Elbow flexion greater than 135°</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P 9</td>
<td>Wrist flexion □ or extension □ greater than 65°</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P 10</td>
<td>Wrist ulnar □ or radial □ deviation greater than 25°</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P 11</td>
<td>Forced pronation □ or supination □ of hand &amp; wrist</td>
<td></td>
<td></td>
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</table>

## OTHER RISK FACTORS

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<th>Yes</th>
<th>No</th>
<th>Comment</th>
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<tbody>
<tr>
<td>O 1</td>
<td>Unusually high tool □ or floor □ vibration</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>O 2</td>
<td>Frequent ladder □ or stair □ climbing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O 3</td>
<td>High exposure to direct pressure □ or mechanical stress □</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O 4</td>
<td>Work with hands over shoulder level for greater than 50% of cycle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O 5</td>
<td>Squat □ or kneel □ for greater than 50% of the cycle</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix D

WINDSOR ASSEMBLY PLANT
TOTAL PLANT SCORECARD
MODEL YEAR Y

<table>
<thead>
<tr>
<th>FORCE</th>
<th># of Operations with RV &gt; 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>F 1  Two handed lift greater than 20lbs</td>
<td>110</td>
</tr>
<tr>
<td>F 2  Vertical travel distance of lift greater than 60°</td>
<td>0</td>
</tr>
<tr>
<td>F 3  Horizontal lifting reach greater than 20&quot; from body</td>
<td>134</td>
</tr>
<tr>
<td>F 4  Two handed carry greater than 30lbs</td>
<td>12</td>
</tr>
<tr>
<td>F 5  Horizontal carry distance of greater than 20ft</td>
<td>20</td>
</tr>
<tr>
<td>F 6  Two handed horizontal push/pull greater than 40lbs</td>
<td>10</td>
</tr>
<tr>
<td>F 7  Two handed vertical push/pull greater than 25lbs</td>
<td>4</td>
</tr>
<tr>
<td>F 8  Trunk rotation with a weight greater than 10lbs</td>
<td>10</td>
</tr>
<tr>
<td>F 9  Wrist rotation while manipulating greater than 6lbs</td>
<td>7</td>
</tr>
<tr>
<td>F 10 One hand horizontal palmer push greater than 15lbs</td>
<td>4</td>
</tr>
<tr>
<td>F 11 Use of hand tool greater than 7lbs</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>POSTURE</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>P 1  Trunk forward flexion greater than 45°</td>
<td>450</td>
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<tr>
<td>P 2  Trunk extension greater than 20°</td>
<td>2</td>
</tr>
<tr>
<td>P 3  Neck flexion or extension greater than 45°</td>
<td>204</td>
</tr>
<tr>
<td>P 4  Trunk or neck side-bent plus twisted</td>
<td>49</td>
</tr>
<tr>
<td>P 5  Shoulder abduction greater than 90°</td>
<td>661</td>
</tr>
<tr>
<td>P 6  Working with hands or arms behind body</td>
<td>3</td>
</tr>
<tr>
<td>P 7  Full elbow extension with shoulder elevation</td>
<td>36</td>
</tr>
<tr>
<td>P 8  Elbow flexion greater than 135°</td>
<td>1</td>
</tr>
<tr>
<td>P 9  Wrist flexion or extension greater than 65°</td>
<td>57</td>
</tr>
<tr>
<td>P 10 Wrist ulnar or radial deviation greater than 25°</td>
<td>158</td>
</tr>
<tr>
<td>P 11 Forced pronation or supination of hand &amp; wrist</td>
<td>82</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OTHER</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>O 1  Unusually high tool or floor vibration</td>
<td>7</td>
</tr>
<tr>
<td>O 2  Frequent ladder or stair climbing</td>
<td>0</td>
</tr>
<tr>
<td>O 3  High exposure to direct pressure or mechanical stress</td>
<td>5</td>
</tr>
<tr>
<td>O 4  Work with hands over shoulder level for greater than 50% of cycle</td>
<td>1</td>
</tr>
<tr>
<td>O 5  Squat or kneel for greater than 50% of the cycle</td>
<td>3</td>
</tr>
<tr>
<td>O 6  Stand on one leg for greater than 50% of cycle</td>
<td>2</td>
</tr>
</tbody>
</table>
Appendix E

Energy Expenditure Calculations

1. **Climbing:** Equation for Walking, up 2 steps at a 45 degree angle, or 2 m (7 ft) on a ramp graded at 50%

**Factors:**
- BW – Body Weight 88kg (196 lbs)
- G - % Grade of floor, ramp or stairs 50% (45°)
- V – Speed of walking (1 m / second)
- T – Time in minutes (.03 min)

**Energy Cost**
\[
= 10^{-2} [51 + 2.54 \times 88 \times (1/1)^2 + 0.379 \times 88 \times 50 \times 1] \times 0.03
\]
\[
= 10^{-2} [1942.12] \times 0.03
\]
\[
= 0.58 \text{ kcal per climbing}
\]

**Standing Cost**
\[
= 0.024 \times BW
\]
\[
= 0.024 \times 88 \text{ kg}
\]
\[
= 2.1
\]

**Total Energy Expenditure Rate:** 1 cycle / minute
\[
= (0.58 \times 1 \text{ / min}) + 2.1 = 2.58 \text{ kcal / min}
\]

2. **Carrying:** Equation for carrying a load of 20 lbs, for 20 ft at a repetition rate of once per minute

**Factors:**
- BW – Body Weight 88kg (196 lbs)
- G - % Grade of floor, 0%
- V – Speed of walking (1 m / second)
- L – Load 9.07 kg (20 lbs)
- T – Time in minutes (.1 min)

**Energy Cost**
\[
= 10^{-2} [68 + 2.54 \times 88 \times (1/1)^2 + 0.379 \times (9.07) \times (1/1)^2 + 11.4 \times (9.07) + 0.379
\]
\[
((0.07 + 88) \times 0 \times 1] \times 0.1
\]
\[
= 10^{-2} [468.68] \times 0.1
\]
\[
= 0.468 \text{ kcal per carry}
\]

**Standing Cost**
\[
= 0.024 \times BW
\]
\[
= 0.024 \times 88 \text{ kg}
\]
\[
= 2.1
\]

**Total Energy Expenditure Rate:** 1 cycle / minute
\[
= (0.468 \times 1 \text{ / min}) + 2.1 = 2.53 \text{ kcal / min}
\]
Appendix F

Sample Epidemiological Data

ErgoMAP Score and Injury Incidence Comparison

<table>
<thead>
<tr>
<th>#</th>
<th>Job Name</th>
<th>Station Number</th>
<th>ErgoMAP Score</th>
<th>Number of CTD Incidence 1999-2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Front Fender Liner Install</td>
<td>661</td>
<td>11</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>Prop Shaft Install</td>
<td>713</td>
<td>11</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>Grill Install</td>
<td>770</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>Muffler Install</td>
<td>716</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>IP Assist Arm</td>
<td>664</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

![Bar chart showing ErgoMAP Score and Number of CTD Incidence 1999-2000 for each job number.]
# ErgoMAP Summary for the Four Operations

## Injury / Risk Factor Rating Report

| Station & Job Name       | F1 | F2 | F3 | F4 | F5 | F6 | F7 | F8 | F9 | P1 | P2 | P3 | P4 | P5 | P6 | P7 | P8 | P9 | O1 | O2 | O3 | O4 | O5 | O6 |   | Total |   |
|--------------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|   |       |   |
| 0661 Front Fender Liner  | 1  |    |    |    |    | 3  | 3  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |  11 |  11 |
| 0713 Prop Shaft Install | 2  |    |    |    |    | 3  | 3  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |  11 |  11 |
| 0770 Grille Install     |    |    |    |    |    |    |    | 3  | 3  |    |    |    |    |    |    |    | 2  |    |    |    |    |    |    |    |  11 |  11 |
| 0716 Muffler Install    |    |    |    |    |    |    |    |    |    | 3  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |  11 |  11 |
| 0664 IP Install Arm     |    |    |    |    |    |    |    |    |    | 2  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |  11 |  11 |

## Legend for Codes:

### Force
- **F1**: Two handed lift > 20 lbs.
- **F2**: Two handed carry > 30 lbs.
- **F3**: Two handed horizontal push/pull > 44 lbs.
- **F4**: Two handed vertical push/pull > 25 lbs.
- **F5**: One handed horizontal palmer push > 15 lbs.
- **F6**: Use of hand tool > 5 lbs.
- **F7**: Truck rotation with a weight > 10 lbs.
- **F8**: Power tool torque rating > 375-lbs / 26°-lbs
- **F9**: Pinch grip > 2lbs

### Posture
- **P1**: Horizontal reach distance > 20°
- **P2**: Trunk forward flexion > 45 degrees
- **P3**: Neck flexion > 45 or extension > 10 degrees
- **P4**: Trunk or neck side bend plus twisted
- **P5**: Shoulder abduction > 90 degrees
- **P6**: Working with hands or arms behind body
- **P7**: Wrist flexion or extension > 45 degrees
- **P8**: Wrist deviation, ulnar > 20 / radial >15 degrees
- **P9**: Pron. or supin. of hand against a resistance

### Other
- **O1**: Noticeably high tool/floor vibration
- **O2**: Climbing up 2 steps, 7 ft ramp or into vehicle
- **O3**: Horizontal cumulative carry distance > 20ft
- **O4**: Repetitive exposure to direct pressure
- **O5**: Work w/ hands above shoulder > 50% cycle
- **O6**: Squat / kneel for > 50 % of cycle

*Each "Y" in other is assigned a value of 2*
## Break Down Of Epidemiological Data

<table>
<thead>
<tr>
<th>#</th>
<th>Job Name</th>
<th>Risk Factor #</th>
<th>RV</th>
<th>Risk Factor Description</th>
<th>Incident #</th>
<th>Injury Type</th>
<th>Investigation Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Front Fender</td>
<td>F1</td>
<td>1</td>
<td>Two handed lift greater than 20 lbs</td>
<td>9045/1999</td>
<td>CTD</td>
<td>Repetitive hammering of liners</td>
</tr>
<tr>
<td></td>
<td>Liner Install</td>
<td>P3</td>
<td>3</td>
<td>Neck extension</td>
<td>5038/2000</td>
<td>S/S</td>
<td>Occasionally lift 10 liners out of bin</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P5</td>
<td>3</td>
<td>Shoulder abduction &gt; 90 degrees</td>
<td>2043/2000</td>
<td>CTD</td>
<td>Continual overhead reach for liner</td>
</tr>
<tr>
<td></td>
<td></td>
<td>O3</td>
<td>2</td>
<td>Exposure to contact stress</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>O4</td>
<td>2</td>
<td>Work with elbows over shoulder</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Prop Shaft</td>
<td>F1</td>
<td>2</td>
<td>Two-handed lift greater than 20 lbs</td>
<td>1027/1999</td>
<td>S/S</td>
<td>Low back strain, from bending over</td>
</tr>
<tr>
<td></td>
<td>Install</td>
<td>P1</td>
<td>3</td>
<td>Horizontal reach greater than 20°</td>
<td>9015/2000</td>
<td>CTD</td>
<td>Low back pain from bending over</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P2</td>
<td>3</td>
<td>Back flexion greater than 45 degrees</td>
<td>3007/2000</td>
<td>S/S</td>
<td>Felt the gun torque away from body</td>
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<tr>
<td></td>
<td></td>
<td>P3</td>
<td>3</td>
<td>Neck flexion greater than 30 degrees</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Grill Install</td>
<td>F9</td>
<td>3</td>
<td>Torque rating for pistol grip &gt; 26°-lbs</td>
<td>1120/1999</td>
<td>CTD</td>
<td>Twisting of neck</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P4</td>
<td>3</td>
<td>Neck side bent plus twisted</td>
<td>11018/2000</td>
<td>CTD</td>
<td>Repetitive reaction of gun</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P5</td>
<td>2</td>
<td>Shoulder abduction &gt; 90 degrees</td>
<td></td>
<td>CTD</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Muffler Install</td>
<td>F1</td>
<td>1</td>
<td>Two handed lift greater than 20 lbs</td>
<td>2013/2000</td>
<td>CTD</td>
<td>Continual reaching to grab clamps</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P1</td>
<td>2</td>
<td>Horizontal reach greater than 20°</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>IP Assist Arm</td>
<td>Zero</td>
<td></td>
<td></td>
<td>N/A</td>
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<td></td>
</tr>
</tbody>
</table>
Appendix G

CONSENT FORM

PROJECT TITLE

An Evaluation of the Validity and Reliability of an Ergonomic Risk Factor Checklist

RESEARCHERS AND INSTITUTION

1. Dr. Jim Potvin, Associate Professor, Faculty of Human Kinetics, University of Windsor (253-3000 x2461; jpotvin@uwindsor.ca)
2. Scott Tolmie, Regional Ergonomic Specialist, DaimlerChrysler (tie 8-852-4085; st4@daimlerchrysler.com)

PURPOSE OF STUDY

The purpose of this study is to determine how reliable the ErgoMAP checklist is when completed by a variety of users at different times on identical operations. Equally important to the reliability between surveyors, is the determination of whether each individual will utilize the tool on their own with the same results time after time.

METHODS

The subjects will be asked to complete the ErgoMAP checklist on six operations within one day, for 4 consecutive weeks. The six operations will be randomly chosen from the truck assembly facility. Instructions for checklist completion will be delivered in the two hour training session and will be very similar to that of the between subjects analysis. They will also be encouraged to skip over or eliminate any line items that are not applicable to the workstation being reviewed at the start of the twenty-minute time period. However, the subjects will be instructed to review two line items for every cycle, as the cycle times in the truck plant are 96 seconds long. If they finish before the twenty minutes are up, they will be able to leave the operation and move on to the next operation. Each subject will be accompanied to the six operations and left alone for twenty minutes at each workstation to ensure no communication between subjects.

The operations chosen have been identified and confirmed with upper management that no changes will take place to the SWI or workstation layout for the four-week observation period. Thereby, controlling the fact that all required work elements will be identical for the six subjects across the four-week period. The only thing that may change during the data acquisition period is the operator performing the operations. This variable of different operators will not be controlled, due to the fact that actual checklist completion in the field must be done this way. The operator's studied at each of the five jobs will be specifically instructed to complete their operations using a normal pace and method. However, each operator will be specifically instructed to complete their operation at their normal pace and method for every checklist conducted.

The checklists will be given to the observer immediately upon completion. A clean checklist will be utilized for each of the six operations across the four-week repetitive measures. The subjects will not be able to review or refer to the previous weeks results on
any of the operations, prior to completing the checklists. The total time that each subject
will dedicate to this research, including the two hour training class is ten hours.

DESCRIPTION OF RISKS
The methods and procedures of this study from data collection to statistical analysis
require no risk to be taken on the part of the subjects. Nor will they be deceived in any way
as part of the research protocol. The subjects will be extremely familiar with the methods of
the study and how to complete the risk factor checklist on assembly operations prior to
embarking on the actual evaluation period.

CONFIDENTIALITY
All data will be kept confidential. Only the researchers mentioned above will know
your identity and personal information. This information will be stored in a secure computer
within the DaimlerChrysler, St. Louis Truck Assembly Plant and will not be discussed or
displayed in any form that would provide an indication of your identity.

FEEDBACK
Procedures and methods pertaining to this study will be communicated both verbally
and in written format prior to the onset of the study. If there has been anything neglected or
something you wish to be further clarified feel free to ask questions at any time before,
during or after the study. If desired, subjects will be given verbal and / or written feedback
once all the data has been analysed.

REMUNERATION
Participation in this study is on a volunteer basis and no remuneration will be provided
to you for the time you spend as a subject in this study.

COMPLAINTS
Any comments or concerns about the study can be directed to the Chair of the
Department of Kinesiology Graduate Studies and Research Committee at the University of
Windsor (519) 253-3000 x2429.
Signed Consent

I, ________________________________ (please print name) have read and fully
understand the information provided in this consent form and the associated information
form provided to me, and voluntarily agree to participate in the described research project.
The purpose and methods of the experiment have been fully described to me by the above-
mentioned researchers. I am aware that I may withdraw as a subject from the experiment for
any reason at any time. I understand that my personal identity will remain confidential
throughout my participation in this study. I am mindful of my right to ask for feedback on
the results at the end of the study. With full knowledge of the foregoing, I agree, of my own
free will, to participate in this study.

_____________________________ Signature of Participant _________________ Date

_____________________________ Signature of Witness
VITA AUCTORIS

NAME: Scott William Tolmie

PLACE OF BIRTH: Windsor, Ontario

YEAR OF BIRTH: 1973

EDUCATION: Brennan High School, Windsor 1987-1992
