Chapter 2

Literature review

2.1 Introduction

In order to get maximum output the workforce has to undergo excessive physical as well as mental pressure. Higher quantity of production involves high level of repetitiveness in jobs. Effort by the researchers has been made to understand the various aspects of CTS and occupational ergonomics specifically for repetitive manual assembly line work.

Musculoskeletal disorders (MSDs) are idiopathic in nature. Worsening of interaction of muscles, nerves, tendons and other supporting structures of the musculoskeletal system due to awkward postures and overload may result in MSDs. Barbara and Hughes conducted a study of upper extremity musculoskeletal disorders in two departments at a pulp and paper mill. There was a statistically significant difference in hand and wrist disorders between the two departments at the p<0.05 level (34.8% in the power and recovery department, and 5.9% in the paper machine area). An important aspect of this study is that the jobs studied were not typical repetitive jobs [Barbara and Hughes, 1996]. Olafsdottir and Rafnsson conducted a study on increase in musculoskeletal symptoms of upper limbs among women after introduction of the flow-line in fish-fillet plants and found that it was related to the increase in monotonous and repetitive nature of the job [Olafsdottir and Rafnsson, 1998]. Work related to upper limb disorders was also studied by Bhattacharyya el al. among workers engaged in fruit processing industry [Bhattacharyya el al., 2011]. Fredriksson et al. studied the impact on musculoskeletal disorders of changing physical and psychosocial work environment conditions in the car-body-sealing department [Fredriksson et al., 2001]. Arocena et al. analyzed the impact of prevention measures and organizational factors on occupational injuries [Arocena et al., 2008]. Dartt et al. studied reliability of assessing upper limb postures among workers performing manufacturing tasks. The purpose of this study was to determine the inter and intra-rater reliability of assessing upper limb postures of workers performing manufacturing tasks. The assessment demonstrated good to excellent reliability for both raters (inter and intra) in all postures of the neck, shoulder, and wrist. Multimedia Video Task Analysis
(MVTA) was used to describe the results [Dartt et al., 2009]. Repetitive strain injury (RSI) is a class of MSDs which is caused by repetitive activities or forceful exertions or pressing against hand surfaces. Kemp et al. did a project involving the evaluation and selection of break reminder software for the management and prevention of RSI in a university environment with a diverse user community [Kemp et al., 2009]. Finneran and Sullivan studied force, posture and repetition induced discomfort as a mediator in self-paced cycle time. A link has been shown between physical risk factors and the causation of musculoskeletal disorders, in particular, high levels of force, deviated postures and repetitive movements. A laboratory study was conducted to test the hypothesis that physical risk factors effect discomfort and that this in turn affects productivity. The results indicate that reducing exposure to force and posture effects should improve productivity in repetitive work [Finneran and Sullivan, 2010]. A prospective study of musculoskeletal disorder has been made among manufacturing workers [Marcus et al., 2014]. Mouzakis et al. in their study concluded that increased intracarpal canal pressures caused by awkward wrist postures imposed during computer work were associated directly with deformation of the median nerve [Mouzakis et al., 2014].

2.2 Prevalence of CTS

Carpal Tunnel Syndrome (CTS) is one of the prominent types of RSI. It is a symptomatic compression neuropathy of the median nerve at the level of wrist/hand. Median nerve compression at the wrist was first depicted by Sir James Paget in 1854 [Chammas et al., 2014]. The chronic CTS occurring mainly at night was described by J. J. Putnam, a neurologist in 1880 [Putnam, 1880; Luchetti et al., 2002]. Continued work is reported with increase in prevalence of the neuropathy.

2.2.1 Identification of CTS risk factors and related issues

Moersch in 1938 has first used the term carpal tunnel syndrome while describing his work on median thenar neuritis [Moersch, 1938]. George Phalen and his group developed provocative tests to recognize the condition of CTS [Phalen et al., 1950; Phalen, 1951].

Barnhart and Rosenstock conducted a carpal tunnel syndrome study on grocery checkers, having a high level of repetitive motion in the course of their work. They studied a cluster of seven cases of the carpal tunnel syndrome felt to be
due to the excessive use of repetitive motion. This cluster of cases, the relation of
the history of their disorder to time at work and a review of the literature suggest
that grocery checkers, because of their excessively repetitive tasks, are at increased
risk for the carpal tunnel syndrome [Barnhart and Rosenstock, 1987]. Their research
group also studied Carpal tunnel syndrome among ski manufacturing workers. Jobs
at a ski assembly plant were classified as repetitive and non-repetitive. The study
revealed that carpal tunnel syndrome is associated with jobs requiring frequent and
sustained hand work [Barnhart et al., 1991]. Study has also been conducted on
prevalence of CTS in agricultural workers, especially those engaged in vineyards
[Mondelli et al., 2010] and at a bottling plant in Nigeria [Ajimotokan, 2009].

Kelly et al. conducted a case study of an inter-collegiate athlete and the
subject is a 21-year-old female inter collegiate volleyball setter diagnosed with CTS.
Purpose of the study was to monitor the progression of her symptom’s severity over
the observation period and to demonstrate that surgery may not always be the
answer. Analysis revealed that only task abstention and conservative medical
treatments is effective in symptoms retardation [Kelly et al., 1995].

Montgomery conducted a study on self examination of carpal tunnel
syndrome by determining the hand grip strength and structural alignment of hand.
Study was conducted on 15 men and 32 women. The participants are taught a
specific method and process of self care techniques for correcting elbows and wrist
alignment. Results revealed that these non surgical self care methods are effective in
dealing with carpal tunnel syndrome [Montgomery, 1995]. Liao made experimental
study on gender differences in hands and sequence of force application on grip and
hand-grip control [Liao, 2014].

A different view was presented by Ingram-Rice who suggested that treatment
of carpal tunnel syndrome should not be focused solely at the wrist. The median
nerve may be compressed anywhere along its course. Neuromuscular trigger points
in various neck and shoulder girdle musculature may imitate the symptoms of carpal
tunnel syndrome. Ultimately poor posture and positioning during activity and rest
can contribute to the symptoms of this syndrome by putting undue strain on upper
body musculature. Once carpal tunnel syndrome has developed, the patient’s health
care providers should work together as a team to identify all potential causes of the
syndrome rather than strictly symptom alleviation [Ingram-Rice, 1997].
Nathan et al. studied the predictors of carpal tunnel syndrome among the industrial workers. Job tasks were classified by both interview and direct observation of work activities. Follow-up evaluations were conducted in 1989 and 1994–1995. The analytic sample consisted of 111 women and 145 men free of CTS in 1984 that were examined at both subsequent contact points. Age, gender, relative overweight, cigarette smoking, and vibrations associated with job tasks were found to increase risk significantly for dominant-hand CTS, whereas presence of an endocrine disorder was marginally related to reduced risk for CTS. Similar to other chronic non-infectious diseases, personal factors may play an important role in determining risk for CTS [Nathan et al., 2002].

Possible implications of typing related posture and activity on carpal tunnel syndrome incidence have been made. The relevant information about CTS risk factors present in data entry task and their implications, with a special emphasis on different extreme postures determined by conventional and alternate keyboards, pointing devices and their role in the development of CTS is also presented. A comparison of several keyboards with respect to design of key switch to reduce force and its effect on carpal tunnel pressure is provided. The assessment of all casual factors, as well as the interrelationship between them in the development process of CTS in data entry task will lead to a decrease in medical and non-medical costs by designing the related equipment ergonomically [Fagarasanu and Kumar, 2003a,b].

Thomsen et al. conducted a study to examine evidence for an association between computer work and carpal tunnel syndrome (CTS). Supplementary, longitudinal studies of low force, repetitive work and CTS, and studies of possible pathophysiological mechanisms were evaluated [Thomsen et al., 2008].

Demirci et al. evaluated the sensitivity of different electrodiagnostic tests on the same hand affected by mild carpal tunnel syndrome (CTS). Clinically diagnosed 189 hands with the CTS and 61 hands of healthy persons were evaluated prospectively. On all hands, median sensory studies from digits 1, 2, 3, 4, and the palm-to-wrist segment from digit 3 and medial motor latency were recorded. Sixty-two hands with delayed motor latency (>4.2 ms) were excluded to ensure that only mild cases were enrolled. Sensory median-radial latency differences from the thumb, median-ulnar latency difference between second and fifth digits, and median-ulnar
latency difference from the fourth digit were calculated in each limb [Demirci et al., 2004].

Handy and Lafreniere studied the effects of coupling repetitive motion tasks with a thermally-stressed work environment at frozen foods manufacturing facility located in the southeastern United States. Complaints from employees at the facility ranged from disorders such as carpal tunnel syndrome to other ailments of components of the upper extremities (e.g., fingers, wrist, arm, elbow, etc). The temperatures ranged from 65˚F to below 32 ˚F in those areas, with the manufacturing processes being very labor-intensive. It was concluded that the premature development of occupational disorders such as carpal tunnel syndrome were manifesting due to the synergistic effects associated with cold-stressed, repetitive production environments [Handy and Lafreniere, 2006].

Bon et al. investigated the prevalence of CTS in full-time and part-time supermarket cashiers exposed to a different weekly duration of biomechanical load. CTS symptoms were defined as past and/or current nocturnal and/or diurnal numbness, tingling, burning or pain involving at least one of the rest three fingers. The prevalence of current CTS symptoms was higher among full-time (31.0%) than in part-time cashiers or controls Multivariate logistic regression analysis confirmed the increased risk for CTS current symptoms in full-time cashiers [Bon et al., 2007].

Yucel et al. studied that Parkinson’s disease (PD) was a chronic progressive disorder which is characterized by rest tremor, akinesia or bradykinesia and rigidity. Carpal tunnel syndrome is caused by compression of median nerve and can occur as a result of repetitive trauma. The aim of this study was to estimate the prevalence of CTS in PD and evaluate the median nerve sonographically. They concluded that PD may pose a risk for the development of CTS due to the repetitive movement of tremor [Yucel et al., 2007].

Spies et al. studied the patients consulting the general practitioner (GP) for the hand/wrist problem in terms of severity of symptoms on a symptom severity scale, and their impact on physical, emotional and social functioning. The method adopted was that the patients consulting their GP with hand or wrist problems were sent a questionnaire containing questions on socio-demographic variables, characteristics of the complaint, physical activity and psychosocial factors. Results revealed that mean age of the 267 participants was 49.3 years and 74% were female. The three most frequently recorded diagnoses were osteoarthritis (17%),
tenosynovitis (16%) and median nerve entrapment (12%). Conclusion obtained was primary care patients with hand or wrist problems report pain and reduced function. Impact on other aspects of perceived health is limited. Severity seems to be associated with socio-demographic, physical and psychosocial factors [Spies et al., 2007].

Toesca A. et al. studied immunohistochemically the expression of estrogen (ER) and progesterone (PR) receptors in CTS and control specimens. Biopsies of transverse carpal ligament (TCL) and flexor tendon synovitis were collected from 23 women and from 7 men undergoing surgery for median nerve decompression at the wrist for CTS. The results demonstrate that ER and PR are present in TCL and flexor tendon synovitis, suggesting a role for sex steroid hormones in the pathogenesis of CTS disease [Toesca et al., 2008]. Development in diagnosis and management of CTS has also been studied and reported [Viera, 2003].

A study that sought to develop quality measures for the diagnostic evaluation and non-operative management of CTS, including managing occupational activities and functional limitations was conducted by Nuckols and co-workers. They suggested nine measures pertained to diagnostic evaluation, such as assessing symptoms, signs, and risk factors and eleven measures pertaining to non-operative treatments, such as the use of splints, steroid injections, and medications. The study concluded that the measures will complement existing treatment guidelines by enabling providers, payers, policymakers, and researchers to assess quality of care for CTS in an objective, structured manner. [Nuckols et al., 2011].

Mechanical insult to the median nerve caused by contact with the digital flexor tendons and/or carpal tunnel boundaries may contribute to the development of CTS. Since the transverse carpal ligament (TCL) comprises the volar boundary of the carpal tunnel, its mechanics in part govern the potential insult to the median nerve. Five different locations on the TCL were tested, three of which were deep to the origins of the thenar and hypo thenar muscles. The average stiffness values at compression sites with muscle attachments were found to be notably lower, with low-strain and high-strain stiffness values of 1.2N/mm (70.5) and 9.7N/mm (74.8), respectively. TCL compressive mechanical properties can help in prove computational models, which can be used to provide insight into the mechanisms of median nerve injury leading to the onset of carpal tunnel syndrome symptoms [Main et al., 2012].
Visser et al. observed that CTS was a common entrapment neuropathy. The aims of the study were to assess the long term effect of a local corticosteroid injection and the prognostic factors. A beneficial effect of more than 6 months was seen in 132 patients (63%), longer than 12 months in 102 patients (48%), and longer than 18 months in 71 patients (34%) [Visser et al., 2012].

Fahmi and El-Shafey in their study established that CTS is more frequent in patients with fibromyalgia (FM) than the normal population [Fahmi and El-Shafey, 2013]. Bardawil et al. studied retrograde degeneration (RGD) of the median nerve forearm segment in patients with CTS and its relation to variable severity of CTS in Egyptian patients [Bardawil et al., 2014]. In a review article it is suggested that CTS diagnosis be conducted primarily from the symptoms and provocative tests. Electroneuromyographic examination may be recommended before the operation or in cases of occupational illnesses [Chammas et al., 2014].

Ilhanli et al. found no difference between one-hand effected and two-hand effected patients and there was no significant correlation between asthetics and pain scales [Ilhanli et al., 2015]. The idiopathic nature of CTS is also established by investigating that in comparison to a common mouse, the vertical mouse and ergonomic mouse pads alter wrist position but do not reduce carpal tunnel pressure in patients with carpal tunnel syndrome [Schmid et al., 2015].

### 2.2.2 Effect of vibration on CTS

Vibration exposure to a person may occurs when he/she stands or sits on a vibration vehicle, machine or surface through person’s feet, operating hand held or automatic vibration tools. Some of the work on effect of vibration on CTS and related occupational injuries is described in following paragraphs.

Hulshof et al. performed an evaluation of 19 epidemiologic studies on the effect of whole body vibration (WBV). This review was restricted to the relationship between WBV and symptoms and/or signs of thoracic and lumbar disorders [Hulshof et al., 1987].

Dupuis and Zerlett studied 352 operators of earthmoving equipment with at least three years of work experience based on interviews and medical examinations. This group was compared with a control group of 315 workers that worked in similar environments with no vibration exposure. The authors concluded that long-
term exposure to whole-body vibrations causes morphological changes in the lumbar spine [Dupuis and Zerlett, 1987].

Wieslander et al. did a study on carpal tunnel syndrome and exposure to vibration. [Wieslander et al., 1989]. Seroussi E. Richard et al. studied trunk muscle electromyography and whole body vibration. They found significantly more average and peak-to-peak estimated torque at almost all frequencies for vibration vs. static sitting [Seroussi et al., 1989].

Bovenzi studied the effects of hand-arm vibration on workers using hand-held vibrating tools. Result of epidemiological, clinical and experimental studies says segmental vibration can cause digital vasospastic attacks (vibration-induced white finger), peripheral sensorineural disturbances (finger numbness, impaired tactile function) and musculoskeletal abnormalities in the hand-arm system (muscle fatigue, degenerative changes in bones and joints). It is likely that different mechanisms are involved in the etiopathogenesis of vibration-induced disorders and, consequently, the symptoms may develop independently though concurrently [Bovenzi, 1989].

Boshuizen et al. examined self reported back pain in tractor drivers exposed to vibration (N = 450) and a reference group of non-exposed workers (N =110). There was a 79% response rate in this study. The highest prevalence odds ratio were found for severe types of back pain, but these prevalence odds ratio did not increase with vibration dose, which might have been due to health-based selection [Boshuizen et al., 1990].

Hammarskjold et al. studied the effect of short-time vibration exposure on work movements with carpenters hand tools. The purpose of this study was to analyse the effect of acute vibration exposure on manual performance. Ten experienced healthy carpenters performed three standardized common tasks (nailing, sawing, and screwing). Vibration exposure seemed to be very individually perceived. Short-time exposure did not seem to influence the performance of well-known tasks [Hammarskjold et al., 1991].

Grant et al. used the motor nerve conduction testing and vibration sensitivity testing as screening tools for carpal tunnel syndrome in industry. This investigation evaluated the use of two portable devices for measuring motor nerve conduction time and tactile sensitivity to 120 Hz vibration in a field setting. The vibration threshold was higher in the carpal tunnel syndrome group than in the other groups;
however, further examination of the data revealed no differences in threshold unless
nerve conduction time exceeded the control mean by at least three standard
deviations. The false-negative rates associated with the tests limit their usefulness in
screening for carpal tunnel syndrome [Grant et al., 1992].

Narini et al. studied occupational exposure to hand vibration in northern
Ontario gold miners. Nineteen underground gold mine drillers who operate vibration
equipment and a control group of 16 gold mill workers without vibration exposure
were evaluated. Assessment included static two-point discrimination, moving two-
point discrimination, vibration threshold, and cutaneous pressure threshold.
Symptoms of vibration white finger were found in 16 miners and 3 control subjects.
The miners had a higher incidence of positive provocative tests at the carpal and
cubital tunnels and higher cutaneous pressure thresholds than the control group.
Significantly higher vibration thresholds were found in the miners versus the control
subjects. A correlation between years of vibration exposure and vibration threshold
was found [Narini et al., 1993].

Burstrom and Sorensson studied the influence of shock-type vibrations on
the absorption of mechanical energy in the hand and arm. The purpose of the
investigation was to compare the influence of shock-type vibration and non-
impulsive vibration on the absorption of mechanical energy in the human hand and
on the grip and feed forces applied by the subjects. The energy absorption has been
measured by use of a specially designed laboratory handle. The grip and feed forces
applied by the subject to the handle were measured simultaneously. In the study two
different frequency weighted acceleration levels were used. The outcome showed
that the vibration exposure levels made a significant contribution to the vibration
absorption as well as to the strength of the grip and feed forces. Moreover, it was
found that the hand forces decrease while the absorption of energy increases during
the experiment. Furthermore, the influence of shock-type exposure gave a
significantly higher hand forces and absorption of energy compared with the non-
impulsive exposure. It was, therefore, concluded that the vibration response
characteristics of the hand and arm differ, depending upon whether the exposure is
of shock or non-impulsive type [Burstrom and Sorensson, 1999].

Astrom et al. compared of the prevalence of symptoms of hand-arm vibration
syndrome (HAVS) and musculoskeletal symptoms in the neck and the upper limbs,
between professional drivers of terrain vehicles and a referent group. Results show
that there is a relation between exposure to driving terrain vehicles and some of the symptoms of HAVS. Increased odds of musculoskeletal symptoms in neck, shoulders and wrists were also found, and it seemed to be related to the cumulative exposure time [Astrom et al., 2006].

Dong et al. studied and hypothesised that the vibration-induced injuries or disorders in a substructure of human hand–arm system are primarily associated with the vibration power absorption distributed in that substructure. The major objective of this study was to develop a method for analyzing the vibration power flow and the distribution of vibration power absorptions in the major substructures (fingers, palm–hand–wrist, forearm and upper arm, and shoulder) of the system exposed to hand-transmitted vibration. A five-degrees-of-freedom model of the system incorporating finger- as well as palm-side driving points was applied for the analysis. The vibration power absorption distributed in the substructures was evaluated using vibration spectra measured on many tools. The frequency weightings of the distributed vibration power absorptions were derived and compared with the weighting defined in ISO 5349-1 (2001). This study found that vibration power absorption is primarily distributed in the arm and shoulder when operating low-frequency tools such as rammers, while a high concentration of vibration power absorption in the fingers and hand is observed when operating high-frequency tools, such as grinders. The vibration power absorption distributed in palm–wrist and arm is well correlated with the ISO-weighted acceleration, while the finger vibration power absorption is highly correlated with unweighted acceleration.

The finger vibration power absorption-based frequency weighting suggested that exposure to vibration in the frequency range of 16–500 Hz could pose higher risks of developing finger disorders. The results supported the use of the frequency weighting specified in the current standard for assessing risks of developing disorders in the palm–wrist–arm substructures. The results were further discussed to show that the trends observed in the vibration power absorptions distributed in the substructures are consistent with some major findings of various physiological and epidemiological studies, which provided a support to the hypothesis of the study [Dong et al., 2007].

Griffin studied measurement, evaluation, and assessment of peripheral neurological disorders caused by hand-transmitted vibration. According to this paper the ‘measurement’ and the ‘evaluation’ of symptoms and signs arising from
exposures to hand-transmitted vibration are required during health surveillance. They are also required when collecting epidemiological data for research into the effects of hand-transmitted vibration. This paper identifies methods of reporting the evaluations of symptoms and signs of peripheral neurological disorders. A single ‘assessment’ (e.g. staging) of the overall effects of hand-transmitted vibration is not essential when monitoring patient health or performing epidemiological research. When judging the outcome from vibration exposure according to a specific criterion (e.g. to decide on removal from work or compensation) an assessment is required, but it should be recognized that a scale devised for this purpose is likely to vary according to the prevailing social, political and economic climate and it will not provide the detail desirable for either health surveillance or epidemiological research [Griffin, 2008].

Hagberg et al. studied Raynaud’s phenomenon in relation to hand-arm vibration exposure among male workers at an engineering plant. The objective of this study was to assess the incidence of Raynaud’s phenomenon in relation to hand-arm vibration exposure in a cohort consisting of male office and manual workers. The baseline population consisted of 94 office and 147 manual workers at an engineering plant. Raynaud’s phenomenon (RP) was assessed at baseline and at follow up (at 5, 10 and 15 years). A retrospective and a prospective cohort analysis of data were done. Hand-arm vibration exposure dose was defined as the product of exposure duration and the weighted hand arm vibration exposure value according to ISO 5349-1. The results indicated that the European directive on an action value for hand-arm vibration of 2.5 m/s² is not too low. Rather, it suggests that employers should take on actions even at exposure values of 1 m/s² [Hagberg et al., 2008].

Xu et al investigated the characteristics of the vibration transmitted to wrist and elbow in the operation of impact wrenches. Six subjects participated in the experiment. Each of them used 15 impact wrenches on a simulated workstation. Triaxial accelerations at three locations (tool handle, wrist, and elbow) and the tool effective torques were measured and used in the evaluations. Results confirmed that the severity of the vibration exposure generally depends on tool and individual, and that the vibrations measured at wrist and elbow reflect the influences of both factors. The fundamental resonance of the hand-arm system in the range of 16–50 Hz is well reflected in the vibration measured at the wrist. The results also demonstrated that vibration exposure duration can be reliably detected from the wrist vibration data.
These findings suggested that the measurement of the wrist vibration can be used as an alternative approach to perform the exposure risk assessment and to monitor and control the exposures in the operation of the impact wrenches [Xu et al., 2009]. Sauni et al. studied to estimate the cumulative exposure to hand-arm vibration (HAV) and the prevalence of clinically diagnosed cases of vibration induced white fingers (VWF) and carpal tunnel syndrome (CTS) in a finish metal workers and to determine the symptoms and clinical tests that would best predict the diagnosis. The exposure time of the VWF cases did not differ significantly from that of the study group as whole, but the cumulative exposure index was significantly higher [Sauni et al., 2009, Sauni et al., 2010]. Khan et al. studied combined effect of noise and vibration [Khan et al., 2009].

Gauthier Francois et al. investigated the vibration of portable orbital sanders and its impact on the development of work-related musculoskeletal disorders (WMSDs) in the furniture industry. The results depicted that the level of vibration to which the workers were exposed was well above acceptable levels defined by recognized standards and directives and that this vibration is combined with many other risk factors, thus representing a risk for the development of WMSDs [Gauthier et al., 2012].

Xu X. S. et al. studied the vibration transmissibility and driving-point biodynamic response of the hand exposed to vibration normal to the palm. Ten subjects (five males and five females) participated in the experiment. A scanning laser vibrameter was used to measure the distributed vibration. This study confirmed that the distributed hand responses generally varied with locations on each finger, vibration frequencies, and applied hand force. Two major resonances were observed in the vibration transmissibility. At the first resonance, the transmitted vibrations at different locations were more or less in phase; hence, this resonance was also observed in the driving-point biodynamic response that measures the overall biodynamic response of the system. The second resonance was observed at the fingers because this resonant frequency varied greatly among the fingers and the specific segments of each finger [Xu et al., 2011].

### 2.2.3 Effect of pinch job on CTS

Investigations on the strength capabilities of the hand began with studies of grip strength. Research continued and expanded to take account of additional
measurements for strength capabilities of the hand, such as pinch strength. Standardization of pinch measurement has progressed, but reaching a reliable measurement standard remains an on-going process. Extensive data on the strength of the fingers during single and multi-digit exertions, analysis of hand strength capabilities and its effect on CTS is available within the literature. An overview of the studies is mentioned below.

Mathiowetz et al. determined clinical norms for adults of varying ages by means of a large sample (n=628) of subjects. Their analysis was focused on differences in maximum voluntary contractions (MVC) produced among individuals in several age groups and of different hand dominance. Comparison of average hand strength of right-handed and left-handed subjects showed only minimal difference. Result shows that the highest grip strength scores occurred in the 25 to 39 age groups. For tip, key, and palmar pinch the average scores were relatively stable from 20 to 59 years, with a gradual decline from 60 to 79 years [Mathiowetz et al., 1985].

Hallbeck et al. examined the effect of wrist position, glove type, age, gender, and dominant/non dominant hand on power grasp and three-jaw chuck pinch force magnitudes for a diverse workforce. Maximal voluntary power grasp and three-jaw chuck pinch force for both the dominant and non-dominant hand were used as the dependent measures of physical capabilities. Six glove types were used as one of the independent variables. For each glove condition, one of five wrist positions was employed: 65° extension, 45° extension, neutral, 45° flexion, and 65° flexion [Hallbeck et al., 1993].

Halpern and Fernandez worked upon measuring maximum fingertip, key, and three-jaw chuck pinch strengths of 20 able-bodied male students between the age of 20 and 34 years using a mechanical pinch strength gauge. It was found that elbow position affected pinch strength but shoulder position did not. Studying the effect of three forearm and wrist positions on maximum voluntary key, fingertip, and three-jaw chuck pinch strength, they found that pinch strength decreased at extreme flexion or extension of the wrist. For all types of pinch strength combined, they found that pinch strength applied in the neutral forearm position was greater than pinch strength applied in the pronated forearm position [Halpern and Fernandez, 1996].

Rock et al. 2001 conducted a study to evaluate grip strength and three-point pinch on forty-one adult volunteers from a local university and local hospital in the
two-day study using a hydraulic hand dynamometer and a hydraulic pinch gauge. The Purpose of this study was to determine whether the use of leather work gloves, vinyl examination gloves, and nitrile examination gloves affect isometric grip strength and isometric three-point pinch in a healthy adult population, compared with no glove use [Rock et al., 2001].

Janson et al. conducted a study to determine the effects of forearm position and outcome score on key, fingertip, and three-jaw chuck pinch strength. Maximum voluntary key, fingertip, and three-jaw chuck pinches were performed by 135 healthy adults (20–88 years old) three times in a pronated, supinated, and neutral forearm position with the right and left hand using a B&L pinch gauge. The highest, first, and mean scores of three pinch forces were recorded. It was found that forearm position affected key and fingertip pinches but not three-jaw chuck pinch [Janson et al., 2003].

Li et al. conducted a study to biomechanically evaluate the motor function of index finger based on multidirectional strengths. The purpose of the study was to develop methods that provide objective, quantitative, systematic, and computer-assisted biomechanical evaluation of the motor function of individual digits based on multi-directional strengths. Their study was focused on the index finger. Their study provides an advanced level of quantification of hand motor function [Li et al., 2003].

Kaya et al. conducted a study to assess site-specific relationship of hand bone mineral density (BMD) with hand size, pinch and grip strength in healthy people aged 19–50 years. A total of 143 healthy volunteers participated in the study (mean age: 34 years). One hundred six were premenopausal women (mean age: 34 years) and 37 were men (mean age: 34 years). Grip and pinch strength was measured by a Jamar dynamometer (Jamar, Irvington, NY). Second, third and fourth middle phalanx BMD were measured on a MetriScan densitometer (Hayward, CA) and mean value of these three phalanges were used in the analysis [Kaya et al., 2005].

Lau and Lp conducted a study to establish handgrip data for right hand dominant normal Chinese subjects. Sixty-four males were studied for their power grip and lateral pinch strengths. They were categorized into non-manual and manual workers. Results showed that both the non-manual and manual workers demonstrated stronger power grip and lateral pinch strengths in their dominant
hands. The 10% rule was applicable only for power grip strength of non-manual workers and lateral pinch strength of manual workers. No significant difference was found between the dominant grip strengths in these two groups of subjects. It was recommended that when assessing the progress and outcome of hand rehabilitation, the occupation and demand level of hand use of the patient must be taken into consideration when using the uninjured hand for comparison [Lau and Lp, 2006].

Burtner et al. analyzed the effect of wrist/hand orthoses on force production, dexterity, and upper extremity muscle recruitment on children with and without cerebral palsy (CP) to determine if splint design affects hand function and muscle activation. Ten children with hemiplegic CP used hands with spasticity and five age-matched control children used dominant and non-dominant hands in three splint conditions (no, dynamic, static) during grip, pinch, and peg-board tests while electromyography (EMG) recorded muscle activation. Preliminary findings suggest that dynamic splints increased function of children with CP while static splints decreased muscle activation at wrist and increased compensatory shoulder muscle recruitment [Burtner et al., 2008].

2.2.4 Presenteeism of tools and techniques for handling data

Data collected with the help of questionnaire, physical and electrodiagnostics is to be processed in a scientific way to have an authentic base for interpretation and conclusion. Researchers have used various statistical tools in their work depending upon sample size, nature to data and objective [Xu et al, 2009; Hamadi, 2012].

Dupuis and Zerlett reported statistically higher prevalence of pathological findings among earth moving equipment operators compared with the control group. After 8 hours of exposure, backache was reported among 45% of the operators (N = 149). The prevalence of backache increased from 35% in the younger group (20–29 years) to 67% in the older group (50–59 years) [Dupuis and Zerlett, 1987]. Bongers et al. examined self reported back pain in tractor drivers exposed to vibration (N = 450) and a reference group of non-exposed workers (N =110) using highest prevalence odds ratio. The highest prevalence odds ratio were found for severe types of back pain, but these prevalence odds ratio did not increase with vibration dose, which might have been due to health-based selection [Boshuizen et al., 1990]. Barnhart et al. presented their result on CTS occurrence in either or both hands in
15.4 % of those workers with repetitive jobs, but only in 3.1 % of those workers with non-repetitive jobs (crude prevalence ratio 4.92, 95 % confidence interval 1.17-20.7) [Barnhart et al., 1991]. Olafsdottir and Rafnsson applied odd ratios for knees and ankles and were found less than one. There was a higher prevalence of symptoms of the upper limbs to the increase of monotonous and repetitive work in the fish industry [Olafsdottir and Rafnsson, 1998]. Gorsche et al. determined prevalence and incidence of carpal tunnel syndrome in a meat packing plant and to explore relation between ethnicity and CTS [Gorsche et al., 1999]. Rock et al in their work used statistically significant test (p < 0.05) for no glove vs, leather glove, no glove vs. nitrile glove, no glove vs. vinyl glove, leather glove vs. nitrile glove, and leather glove vs. vinyl glove [Rock et al., 2001]. Koley et al. (2009) have used statistical significance (‘p’ and ‘t’ values) amongst demographics and hand grip strength [Koley et al., 2009]. Few researchers have determined prevalence odds ratios (POR) and determined and adjusted for age and nicotine use in their study on MSDs [Astrom et al., 2006].

Atroshi et al. made analysis with receiver operating characteristic (ROC) curves to compare the diagnostic accuracy of the nerve conduction tests in distinguishing the persons with clinically certain CTS from the asymptomatic persons [Atroshi et al., 2003]. Geere et al. have reported descriptive statistics enabling calculation of effect sizes to compare the relative responsiveness of grip and pinch strength within study samples [Geere et al., 2007]. Seror in hi work found that standard deviation (S.D.), when compared to mean values makes normal and abnormal data overlap considerably and produces many false negatives when the specificity is high and many false positives when the sensitivity is high [Seror, 2008]. Ajimotokan opted a five-step regimen method to conduct CTS related evaluation [Ajimotokan, 2009].

Barbara and Hughes found that there was a statistically significant difference in hand and wrist disorders between the two departments of a paper mill at p<0.05 level (34.8% in the power and recovery department, and 5.9% in the paper machine area). Multiple logistic regression models showed a significant relationship between the use of a steel lance and shoulder disorders [Barbara and Hughes, 1996]. By making use of logistic regression analyses, Nathan A. Peter et al. found that greater age, female gender, relative overweight, cigarette smoking, and vibrations associated with job tasks significantly increase risk for dominant-hand CTS,
whereas presence of an endocrine disorder was marginally related to reduced risk for CTS [Nathan et al., 2002]. The logistic regression was also used by Babski and Young to demonstrate result that for diagnosed CTS, hand movement (HM) were the only repetition measure to have a significant relationship, and were tentatively concluded to be the best predictor [Babski and Young, 2002].

Difference in proportions of CTS symptoms and cases amongst the super market cashiers has evaluated by the Pearson’s chi-square (2) test. Univariate and multivariate logistic regression analyses was used to determine the impact of weekly exposure The intersection of the two values fell on the threshold limit value line, conforming the possible exposure to biomechanical risk factors for CTS. The prevalence of current CTS symptoms was higher among full-time (31.0%) than in part-time cashiers. Multivariate logistic regression analysis confirmed the increased risk for CTS in full-time cashiers [Bon et al., 2007]. Differences in demographic and electrophysiological findings between groups of agricultural workers were studied by Mondelli and co-workers. They performed multiple linear regression analysis to eliminate the influence of potential confounding factors (age, sex, BMI, clinical severity of CTS) on the results of univariate difference analysis. The differences remained significant after adjusting the results for confounding factors [Mondelli et al., 2010].

Strain index (SI) and survey results in a compact disc manufacturing and packaging unit were analyzed by the chi-square goodness-of-fit test, and the employees significantly agreed that all of the proposed prevention methods would lead to fewer CTS incidents over time, which was verified by the level of significance shown by the chi-square goodness-of-fit test [Smith and Savage, 2008]. The method was adopted by to assess hazardous operations that contribute to CTS [Gabriel et al., 2008]

Narini P. Phillip et al. studied occupational exposure to hand vibration in northern Ontario gold miners. A correlation between years of vibration exposure and vibration threshold was found [Narini et al., 1993]. Kaya et al. have used correlation analysis and revealed that there is a moderate correlation between hand-grip strength and hand bone mineral density BMD in men [Kaya et al., 2005]. Arocena et al. used negative regression based on a sample of 213 Spanish industrial establishments, defining a constant random parameter to account for non-observable heterogeneity in the way to reduce the number of occupational injuries [Arocena et al., 2008]. Xu
et al. correlated the accelerations measured at the wrist and elbows with the ISO frequency-weighted tool acceleration [Xu et al., 2009]. Moghtaderi and Ghafarpoor in a case study using correlation analysis established that there was no statistically significant correlation between subgroups of CTS patients and control group [Moghtaderi and Ghafarpoor, 2009].

Hallbeck et al. have used analysis of variance (ANOVA) for the dependent variable power grasp and demonstrated that gender, glove type, hand, and wrist position had a significant impact on the magnitude of force exerted [Hallbeck et al., 1993]. Coury et al. compared the repetition of wrist movements and force produced by workers when packing pencils in manual, semi-automated and automated industrial operations. ANOVA was used for analyzing the results. The analysis showed significant differences in frequencies of wrist motion (p<0.05) between the production systems [Coury et al., 2000].

A laboratory study was conducted by Finneran and Sullivan to test the hypothesis that physical risk factors affect discomfort and that this in turn affects productivity. Participants performed repetitive grip exertions involving combinations of three levels of grip force (10, 20 and 30% MVC), repetition (10, 15 and 20 repetitions per minute) and wrist posture (50% flexion/extension and neutral). Treatments were performed for 10 min. after which the participants were instructed to adjust the cycle time to a self-selected-pace (the productivity measure) for the remaining 10 min. Analysis of Variance (ANOVA) was performed on the data and the results indicated that each of the main factors had significant effects on discomfort at 10 min. Self-pace cycle time was significantly affected by force and posture. Correlation and regression analysis revealed a strong relationship between discomfort and self-pace cycle time. Path analysis revealed that discomfort was a mediating variable in the relationship between the primary risk factors and self-paced cycle time [Finneran and Sullivan, 2010].

Using a variation of the well-established appropriateness method, Nuckols et al. developed draft quality measures for the diagnostic evaluation and non-operative management of CTS [Nuckols et al., 2011]. Xu et al. presented a methodology that could be used to integrate ergonomic measures of upper extremities into assembly line design problems. Linear models are developed to link work-worker assignment to the upper extremity ergonomic measures based on a guideline from American Conference of Governmental Industrial Hygienists. These linear models allow
ergonomic and productivity measures to be integrated as a mixed-integer programming model [Xu et al., 2012]. Linear regression analysis of hospital episode statistics has been used for elective hand surgery [Bebbington and Furniss, 2015].

2.2.5 Electro-physiological / electro diagnostic testing and its analysis

Small electrical currents are generated by muscle fibres prior to the production of muscle force. These currents are generated by the exchange of ions across muscle fibre membranes, a part of the signaling process for the muscle fibres to contract. The signal called the electromyogram (EMG) can be measured by applying conductive elements or electrodes to the skin surface, or invasively within the muscle [Seroussi et al., 1989]. Surface EMG is the more common method of measurement, since it is non-invasive and can be conducted by personnel other than medical doctors, with minimal risk to the subject.

Electromyogram is one of various bioelectrical signals generated from the human body. It has been actively studied for the human muscle analysis. sEMG, BIOPAC Systems and MP45 have been used to generate signals from the APB muscle. Devices are being developed for measurement of surface electro-myography for clinical use [Chatterjee, 2012].

Advent of modern electronics and the process of differential amplification have enabled the measurement of EMG signals of low noise and high signal fidelity (i.e. high signal to noise ratio). With differential amplification, it is now possible to measure the full effective bandwidth of the EMG signal. Typical band pass frequency ranges are from between 10 and 20Hz (high pass filtering) to between 500 and 1000Hz (low-pass filtering).

High-pass filtering is necessary because movement artefacts are comprised of low frequency components (typically <10Hz). Low pass filtering is desirable to remove high-frequency components to avoid signal aliasing [Gerdle et al., 1988].

In the past, it was common to remove power-line (A/C) noise components (i.e. either 50 or 60Hz) by using a sharp notch filter. There are problems with notch filtering because EMG has large signal contributions at these and neighbouring frequencies. The result of notch filtering is the loss of important EMG signal information, so notch filtering should be avoided as a general rule. Amplification is also necessary to optimize the resolution of the recording or digitizing equipment [Gerdle et al., 1988]. Amplifiers of high quality have adjustable gains of between, at
least, 100 and 10,000 to maximize the signal to noise ratio of the EMG signal during each recording. This range of gains provides the sufficient range of amplifications for surface EMG signals which can range typically from 0 to 6mV peak to peak. The quality of the EMG signal, in part, depends on the characteristics of the amplification process [Ahmad et al., 2012]. Feature extraction using wavelet transform is also reported for the electrical signal obtained from the subjects [Saxena et al., 2002]. Image processing has also been used in medical feature based evaluation [Shrimali et al., 2009].

Sheean et al. examined 66 hands referred with suspected carpal tunnel syndrome (CTS) using the second lumbrical-interosseous distal motor latency difference (2LI-DML) as well as standard tests. Forty-nine cases of CTS were diagnosed by the standard tests, 48 of whom had an abnormal median-ulnar palmar velocity comparison and 48 had an abnormal 2LI-DML. The results of these 2 tests were closely correlated. The 2LI-DML supported the diagnosis of CTS in all cases except one, where the result was borderline. In one suspected case the 2LI-DML was the only abnormality. In 9 severe cases no median palmar responses could be obtained but an abnormal 2LI-DML was found. They concluded that the 2LI-DML is as sensitive as the palmar comparison and thus will support the diagnosis of CTS made by standard tests. It has also proved useful as a quick and simple screening test for CTS on the asymptomatic side [Sheean et al., 1995].

Cherniack et al. studied a comparison of traditional electrodiagnostic studies, electroneurometry, and vibrometry in the diagnosis of carpal tunnel syndrome. In 49 patients (98 hands), referred to an electrodiagnostic laboratory, assessments were made by conventional nerve conduction studies on the upper extremity and by two more portable modalities, namely electroneurometry (skin surface electrical stimulation of the motor nerve) and single-frequency (120 Hz) vibrometry. Tests were performed on median and ulnar nerves. Correlations with motor nerve conduction studies for each screening test on the median nerve were \( r = .81 \) for the electroneurometer and \( r = 0.48 \) for the vibrometer. When carpal tunnel syndrome was diagnosed either by clinical criteria only or by nerve conduction abnormality, the association with electroneurometry was characterized by high sensitivity and low specificity, while the opposite relationship prevailed with vibrometry. These associations were highly dependent on the methods used to select normal values from a reference population [Cherniack et al., 2008].
Study by Guglielmo et al. described that carpal tunnel syndrome (CTS) standard measurement of median distal motor latency and sensory conduction does not distinguish whether low amplitude responses are due to axonal degeneration or demyelination. In 88 control and 294 CTS hands, amplitude and duration of compound muscle action potential (CMAP) were recorded. In 16% of CTS hands there was an abnormal amplitude reduction without increased duration of CMAP or SNAP from wrist stimulation indicating partial conduction block. In 148 hands distal motor latency to abductor pollicis brevis and/or sensory conduction to digit 2 were abnormal. In the remaining 146 hands wrist to palm motor conduction was less than 35 m/s in 22.6% and wrist to palm sensory conduction were less than 45 m/s in 13% of population. At least one segmental conduction was abnormal in 27% of hands [Guglielmo et al., 1997].

In the subsequent year Girlanda et al. made Electrophysiological studies in mild idiopathic carpal tunnel syndrome. Many techniques have been reported to improve the diagnosis of carpal tunnel syndrome (CTS), but there is no agreement on the diagnostic yield of these different methods. They used an electrophysiological protocol including the assessment of the orthodromic sensory conduction velocity of the median nerve along the carpal tunnel. They have also made a comparison of median and ulnar sensory conduction between the ring finger and wrist. The distoproximal ratio calculation was the most sensitive technique (81%), but was also the least specific. The ‘inching test’, even though less sensitive, had the advantage of localizing focal abnormalities of the median nerve along the carpal tunnel. The best procedure for electrodiagnosis of mild CTS was to combine the median/ulnar comparison test with calculation of the disto-proximal ratio [Girlanda et al., 1998].

Donaldson et al. proposed a wider integration of physiological systems in the etiology and maintenance of CTS that links muscular dysfunction in the neck and possibly elsewhere to dysfunction at the CT. Significant subsets of individuals who develop CTS have a primary contribution from muscular dysfunctions rather distal to the CT itself [Donaldson et al., 1998].

Atroshi et al. performed nerve conduction tests on the symptomatic and the asymptomatic persons by blinded examiners. Analysis with receiver operating characteristic (ROC) curves was used to compare the diagnostic accuracy of the nerve conduction tests in distinguishing the persons with clinically certain CTS. Using the clinical diagnosis of CTS as the criterion standard, nerve conduction tests
had moderate sensitivity and specificity and a low positive predictive value in population-based CTS. Measurement of median-ulnar sensory latency difference had the highest diagnostic accuracy [Atroshi et al., 2003].

Demirci et al. evaluated sensitivity of different electrodiagnostic tests on the same hand affected by mild carpal tunnel syndrome (CTS), 189 hands with the clinical diagnosis of CTS and 61 hands of healthy persons prospectively. Sensory studies of only one median innervated digit failed to diagnose 15–20% of hands. Conduction velocity at the palm-to-wrist segment was the most sensitive, diagnosing 99% of cases. Segmental measurement has the highest diagnostic yield and may be used first in the evaluation of CTS [Demirci et al., 2004].

Violante et al. conducted a study on levels of agreement between different sets of median nerve conduction studies (NCS) and symptoms of carpal tunnel syndrome (CTS) in at-risk subjects. With the importance of the dominant hand in working populations, the data can be used as an informative NCS parameter for occupational studies on CTS [Violante et al., 2004].

Electrodiagnosis (EDX) is considered as the gold standard for CTS diagnosis. Seror studied scope of sonography in diagnosis of carpal tunnel syndrome (CTS). They found that sonography is non-interpretable in only 10 to 15% of the population, and it affirms the median nerve lesion at the wrist in 55% of cases when EDX does it in more than 90% with common tests. The sonography and EDX may be complementarily to each other but cannot replace proper EDX performed for upper limb parenthesize [Seror, 2008].

Sernik et al. studied the most adequate cut-off point for median nerve cross-sectional area and additional ultrasound features supporting the diagnosis of carpal tunnel syndrome (CTS). Median nerve cross-sectional area was obtained using direct (DT) and indirect (IT) techniques. Median nerve echogenicity, mobility, flexor retinaculum measurement and the anteroposterior (AP) carpal tunnel distance were assessed [Sernik et al., 2008].

Wilder-Smith et al. studied that sensory symptoms within the median-nerve distribution was a primary clinical diagnostic criterion for the diagnosis of carpal tunnel syndrome (CTS). The distribution of the sensory symptoms in CTS varies from patient to patient. The study described that in carpal tunnel syndrome, sensory symptom distribution is strongly dependant on the degree of electrophysiological median nerve damage [Wilder-Smith et al., 2008].
Aygul et al. evaluated prospectively the sensitivities of conventional and new electrophysiological techniques and investigate their relationship with the body mass index (BMI) in a population of patients suspected of having carpal tunnel syndrome (CTS). The sensitivity of the median sensory nerve latency (mSDL) and median motor distal latency (mMDL) were 75.8% and 68.5%, respectively. Measurements of all nerve conduction studies (NCSs) parameters were abnormal in obese than in non-obese patients when compared to the BMI [Aygul et al., 2009].

Moghtaderi and Ghafarpoor suggested that there may not be any association between CTS and ulnar nerve compression at the wrist. It was also suggested that different racial groups and multiple techniques in performing nerve conduction studies and dissimilar cutoff values for the diagnosis of entrapment neuropathies are the major causes of ambiguity in the literature [Moghtaderi and Ghafarpoor, 2009].

Mondelli et al. performed a retrospective cross-sectional electrophysiological test to study prevalence of CTS. They found that thenar motor fibers were more affected, presumably due to chronic compression on the thenar branch. [Mondelli et al., 2010].

Tawfik et al. assessed the utility of second lumbrical-versus-interosseus (2L-INT) in the electrodiagnosis of CTS and evaluated its sensitivity in comparison to other routine median motor and sensory studies [Tawfik et al., 2013].

Study on median nerve cross sectional area in diagnosis of CTS has been carried out by Zidan et al [Zidan et al., 2013]. Castro et al used ultrasonography in the diagnosis of CTS [Castro et al., 2015]. Sensitivity of electromyography and ultrasonography in diagnosing CTS in comparison with physical examination has also been investigated by researchers [Filho et al., 2014]. Saba found that median versus ulnar medial thenar motor (MTM) can be considered as a useful neurophysiological test in combination with other median versus ulnar comparative tests for confirming the diagnosis of CTS beside other well known electrophysiological tests [Saba, 2015].

Lee et al. demonstrated that dynamic carpal tunnel pressure (CTP) measurement could be a significant approach to evaluate the pathophysiological phenomenon of CTS. Two-point discrimination (2-PD) test might be a good tool to reflect the most pathological site of CTP. The 2-PD and duration of symptoms are correlated with CTP value in specific areas with hand postures [Lee et al., 2016].
2.3 Problem formulation and methodology

Having carried out an extensive survey of literature in line it has been found that a sort of literature on systematic study of CTS is available but that related to assembly line of manufacturing industry has been very rarely found. Northern part of India, especially Punjab, Haryana and National Capital Territory is hub of small and medium scale industry. Study of CTS under this (northern part of India) socio-physiological condition is an unexplored area of research. There appears a room for

i) investigating the effect of repetitive postural movements of upper extremities on prevalence of CTS among workers engaged in manual assembly line of manufacturing unit in northern part of India. Exposure to hand arm vibration and pinch on prevalence of CTS in the said unit also require detailed investigation.

ii) investigating prevalence of occurrence of CTS by repetitive use of finger dominated manual work apart from other upper extremities (e.g. hand, wrist and shoulder), in the manufacturing units.

iii) study on effect of ergonomic work environment on prevalence of CTS in assembly line of manufacturing unit.

Looking into the research gaps, objectives for the present work were decided and have been mentioned in Chapter 1. The objectives have been achieved by proceeding in following manner.

- Selection of Industry and study of job nature therein.
- Design of questionnaires/ health surveillance form to be filled by subject/workers.
- Collection of test data through appropriate instrument and questionnaire.
- Conducting physical tests (Phalen and Tinel) on the workers.
- Acquisition of sEMG data with the help of surface Electromyography machine.
- Analysis of the data using statistical tools.
- Outcome of research.