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ORIGINAL ARTICLE

Empirical Study of the Manual Performance Disability Caused by Exposure to Extreme Cold Air among Auto Mechanic Workers

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ABSTRACT
A decrease in body temperature can impair manual performance leading to a lowered capacity to carry out a certain activity. This study was aimed to analyze the extent effects of extreme cold air exposure on workers' manual performance. The study population was consisted of 50 outdoor auto mechanics that were participated in two experiments carried out in winter and spring. Following a standard method, air environmental factors in each workstation and the physiological responses of the participants were measured. Touch sensory test was conducted to determine the sensory function of the hand. The grip strength and manual dexterity tests were also performed to assess manual work disability. The hand grip and pinch grip strength of the auto mechanics were reduced by 10.3% and 10.1% in cold air, respectively, as compared with the neutral air. Manual dexterity of the auto mechanics was also decreased from 6.3% to 8.8 % in cold air, as compared with neutral air. The prevalence of finger sensation disorders in the auto mechanics was 62% in cold air, while it was only 4% in neutral air. There was also a significant correlation between finger skin temperature and manual dexterity (r=-0.80, p<0.01), hand grip strength (r=0.74, p<0.01), and pinch grip strength (r=0.79, p<0.01). There was also a significant correlation between finger sensory function and manual dexterity (r=0.65, p<0.01). During extreme cold air exposure, the physiological and sensory changes have significantly reduced the manual performance of the auto mechanics. This study were able empirically provide a database for further researches on other aspects of the performance of workers exposed to cold air.
KEYWORDS: *Manual performance, Outdoor workers, Extreme cold air, Occupational exposure*

INTRODUCTION
Human exposure to cold air is a main health hazard in outdoor work in some regions world widely, especially during the winter [1-2]. Cold stress happens due to an imbalance between the heat produced in body through metabolism and the heat transferred to the environment by different mechanisms [3]. The initial physiological response to cold exposure is a peripheral skin vasoconstriction and a reduction in skin blood flow. This can reduce convective heat exchange between the human body's core and shell, and therefore effectively increases insulation by the body's shell [4-5]. Strong vasoconstrictions can lead to a rapid loss in hand and foot skin temperature. This may cause damage to manual dexterity, tactile sensitivity, and muscle contractile characteristics and it is associated with pain and a reduction in gross motor performance [6-7]. An impairment of manual performance can lead to an inadequate capacity to conduct a special task within a defined time, or an increase in human errors when doing activities.

Exposure to cold air can also affect finger dexterity, hand and pinch grip strengths, and the adduction /abduction of hand fingers. These impairments can be attributed to the cooling of peripheral tissue of human body [8]. It is said that a slight reduction of skin temperature below the optimum temperature i.e. 33ºC can cause tactile sensation loss. The critical temperature is 20ºC for hand skin and 28ºC for muscles; a further temperature loss quickly affects nerves [9-10]. It is reported that a finger skin temperature below 20°C can impair manual performance [11].

Heus et al. were showed that the manual performance of workers is related to finger and hand skin temperatures [9]. Harazin et al. revealed that the

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mean vibro tactile perception threshold among the participants with cold hands was significantly higher than the counterpart value among the participants with warm hands [12]. Ozaki et al. reported that a lowered work ability and manual dexterity may increase human errors and consequently the risk of accidents for those who work at cold [13]. Therefore, manual dexterity is considered as a critically significant factor to achieve suitable work performance and safety [14]. Carlsson et al. studied the neurosensory and vascular functions of military in cold winter conditions. The army man showed a decrease in perception and sensitivity to touch, warm, cold, and vibrations in both the feet and hands. Moreover, the prevalence and severity of white fingers, cold sensations, and hand discomfort and pain increased when they were exposed to cold [15]. Hand finger temperature can be considered to be a main indicator of hand and finger dexterity. Moreover, manual dexterity and grip strength on both hands can be considered as the most important indicators of manual ability [16].

It is not possible to avoid working at cold weather and a large number of workers are continuously exposed to cold air environments. Extremity cooling can cause a progressive decrease in performing manual tasks, especially those involving fine finger coordination, and manipulation. The cold affects hand manual dexterity; in addition, cutaneous sensitivity can lead to deterioration in the performance of workers such as auto mechanics who take different manual tools and perform fine tasks with push buttons, knobs, keys, screws, nuts, and bolts [16]. The protective gloves can alleviate the adverse effect of cold, however, in some tasks such as those performed by auto mechanic, high insulation materials can limit hand mobility, reduce hand strength, and limit the contraction velocities of muscles. Since few empirical studies have been conducted on the effect of cold stress on work ability, it seems that further investigations are necessary. Some previous studies were described the effects of cold air on body's physiological response and physical performance [6-17]. However, epidemiologic data on manual performance of workers exposed to cold air are scarce. This study was aimed to investigate the effect size of exposure to extreme cold air on manual performance in typical workers with manual activities.

MATERIALS AND METHODS

In this cross-sectional study, auto-mechanics who were continuously working in the outdoor environment in Hamadan (a western province in Iran) were selected as the study population. The data were collected from 50 workers in two steps, in winter as typical cold air condition and spring as typical neutral air condition in 2017. Data collections for 50 volunteer in each season were performed approximately 10 days. Since the studied mechanic workers were obliged to carry out tasks requiring dexterity, they were not using any type of gloves. The current study was approved by the Ethics Committee of Hamadan University of Medical Sciences (ethic code: IR.UMSHA.REC.1395.354). In addition, all the participants completed and signed the informed consent form. We excluded participants who had a history of previous hand injuries due to different accidents and those who were taking certain medications. None of the studied participants had a history of cigarette smoking and alcohol consumption.

Measurement of environmental air factors: In each workstation, the environmental air factors were measured and recorded. The environmental air factors including dry-bulb temperatures and air velocities were measured by means of a portable hot wire thermo anemometer (KIMO instruments, model VT50) in the workstation of each subject. Cold stress indices included wind chill index (WCI), chilling equivalent temperature (tch) and IREQ were also calculated as follows:

The wind chill index (WCI) combines the effects of air temperature and air velocity into a single index or wind chill value. Equation (1) was used to estimate the rate of cooling of exposed workers [1]

$$WCI = (10\sqrt{v} + 10.45 - v)(33 - t_a) \quad kcal \quad {}^{-2}m \quad h^{-1} \qquad (1)$$

Wind chill equivalent temperature (WCT) estimates frostbite times for exposed facial skin was also determined based on air temperature and air velocity using the frostbite risk guide table. Required Clothing Insulation Index (IREQ) is estimated based on two indices included clothing insulation required for heat balance (IREQ min) and clothing insulation required to provide comfort (IREQ neutral). These indices were calculated from graphs of IREQ values over a range of conditions such as function of ambient operative temperature at four levels of metabolic heat production [1].

Measurement of body physiological responses: Working metabolism of the subjects was determined the basis of ISO 8996 [18]. Clothing insulation (Icl, Clo unit) of the participants was determined based on ISO 9920:2007 [19]. The height (Height in meter) and body weight (Weight in kg) were measured and body mass index (BMI) was calculated. Skinfold measurement was used to assess body compassion of subjects. This method requires a tester to use calipers to measure different locations around the body. The caliper (model 01128, LAFAYETTE Instruments) was used and the percentage of body fat was determined based on Equation (2) as follows [20].

Body fat (%) = (0.43×X1) + (0.58×X2) +1.47 (2)

Where, X1 and X2, in millimeter, are the skinfolds thickness of triceps and shoulders, respectively.

Body physiological responses of the subjects in winter and spring were measured in accordance with ISO 9886 at least after two hours of daily work in the morning [21]. For measuring tympanic temperature, an ear thermometer (TH839S, OMRON Instruments) was used. For subjects dominant hand, finger and palm temperatures were measured using infrared thermometer (KIRAY 300, KIMO Instruments). Further, using heart rate monitor device (FT1, POLAR Instruments), heart rate of subjects was measured.

Measurement of manual performance

Finger sensory function: The cutaneous sensation levels through fingers can be determined using finger touch sensory test which was performed by Semmes-Weinstein Monofilaments. This is a non-invasive method with reliable and unbiased

(a) (b)

Fig. 1. The participants performing finger sensation (a) and grip strength (b)

outcome. In order to help the subjects completely focus on the testing instruction, the test i.e. touch sensory evaluation, was carried out in a quiet room.

The auto mechanics were asked to look away and say “yes” when the stimulus was felt. This test was started from small monofilaments and was finished to large monofilaments .It also covered a range from distal to proximal digits. The filament was pressed at a 90° angle against the skin until it bows. Figure 1-a shows how the workers carried out the touch sensory tests. When a worker responses to the stimulus in all the sites of testing, normal cutaneous sensation was recorded and the test was finished. If a worker did not response to the stimulus, the next largest monofilament was used and the process was performed once again. Semmes-Weinstein monofilament test includes a normal level: 1.65-2.83, diminished light touch level: 3.22-3.61, diminished protective sensation level: 3.84-4.31, loss of protective sensation level: 4.56-6.45, and deep pressure sensation level: 6.65 [22].

Hand grip strength: Jamar Hydraulic Hand Dynamometer (Model J00105, Lafayette Instrument) was used to measure the maximum grip strength of hand. The auto mechanics were asked to keep their elbow in a 90° angle, in a neutral position of their wrist, and with their underarm backed by the desk. Afterwards, they were asked to use each hand to grasp the handle three times in 10-seconds intervals. The measurements were recorded in kg and the mean of the three records was calculated [22-23].

Pinch grip strength: Jamar Style Hand Pinch Gauge (Model J00111, Lafayette Instrument) was used to measure pinch grip strength (Figure 1-b). The subjects were asked to grip the pinch gauge in their hand and requested to pinch it with their fingers three times at 10-seconds intervals. Then, the mean value of the three measurements was calculated. The highest measured value was set as the participant’s pinch strength in kg [22-23].

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Manual dexterity: Manual dexterity was determined through performing Complete Minnesota Dexterity Test (CMDT). This test examines Placing Test and Turning Test. Each test can be repeated up to four times. After completing one trial, the board must be re-set for the following trials. The test time is recorded in seconds on the score sheet designed for each trial. The final scoring is interpreted using total seconds of all the trials. The subject performed all the tests in a standing posture (Figure 2). The placing test was employed to evaluate the speed of putting disks from the top board into the bottom board using the dominant hand. The starting point was selected in a place board's table 10 inches away from the edge with the disks inserted into the holes in the board. The turning test was employed to evaluate the speed of picking up disks with one hand and turn them with the other hand before replacing disks into the holes of the board [11]. It should be noted that, measurement of manual performance criteria were performed at least after two hours of daily work in the morning

Statistical analysis: The data was analyzed using SPSS version 21. The used statistical tests were included Paired-Samples T-Test, Pearson correlation coefficient, and linear regression. The significant level was set at 95% for all the statistical tests.

Fig 2. Participants' manual performing dexterity tests

RESULTS

The age means (±SD), and work experiences of the participants were 41.06±9.80 years and 17.66±8.16 years, respectively. The BMI mean (±SD) and fat percentage of the participants were 24.76±2.04 and 32.60±3.14 percent, respectively. Table1 presents the descriptive statistics of environmental air factors in the studied environments.

Descriptive statistics of cold stress indices in the studied environments were presented in Table 2. Based on the results of WCI index, the studied employees were exposed to an interval between cool, very cool and warm to pleasant conditions in winter and spring, respectively. It can be concluded from Table 2 that the mean of Icl value (clothing clo) is lower than IREQmin, hence, workers' clothing haven't enough thermal insulation in exposure to cold condition. The results of the wind chill temperatures also showed a low risk of frostbite for most workers which are exposed to cold air.

The physiological responses of the participants in the two studied weather conditions were presented in Table3. The result showed statistically significant differences among subjects' body physiological characteristics in cold and neutral air conditions.

Table 1: Descriptive statistics of environmental air variables in the studied environments

Environmental air variables		Mean ± SD	Minimum	Maximum
Air temperature (ºc)	Cold air	-1.97±0.96	-3.20	0.00
	Neutral air	27.27±1.80	24.00	31.00
Relative humidity (%)	Cold air	61.46±7.47	46.00	75.00
	Neutral air	22.90±1.70	20.00	27.00
Air velocity(m/s)	Cold air	0.15±0.09	0.04	0.32
	Neutral air	1.63±0.40	1.00	2.10

Table 2: Descriptive statistics of cold stress indices in studied environments

Cold stress indices	Conditions	Mean & SD	Min	Max
WCI(kcal $^{-2}$m h)	Cold air neutral air	489.97 ± 47.68 122.69 ± 36.47	409.53 38.90	568.32 189.77
WCT (̊c)	Cold air	-3.00 ± 1.50	-2.00	-5.00
IREQ min (clo)	Cold air	2.04 ± 0.25	1.65	2.40
Icl (clo)	Cold air	1.85 ± 0.20	1.55	2.25
IREQ neutral (clo)	Cold air	2.18 ± 0.25	1.76	2.70

Table 3: Participants body physiological characteristics descriptive statistics

Physiological parameters	Cold air	Neutral air	p-value
Body core temperature (ºc)	35.50±0.31	36.32±0.49	<0.01
Heart beat (beat/min)	78.04±4.00	67.00±4.95	<0.01
Finger temperature (ºc)	21.46±2.39	33.85±0.93	<0.01
Palm temperature (ºc)	25.60±2.56	34.41±0.64	<0.01

Table 4: Participants grip strength tests results

Types of tests	Cold air	Neutral air	p-value	Winter/Spring ratio (%)
Hand grip strength (kg)	40.08±4.15	44.70±5.18	<0.01	89.66
Pinch grip strength (kg)	21.14±1.92	23.52±2.87	<0.01	89.88

Table 5: Participants manual dexterity criteria results

Types of tests	Cold air	Neutral air	p-value	Winter/Spring ratio (%)
Placing test (second)	171.38±8.33	186.71±11.46	<0.01	91.2
Turning test (second)	135.45±6.76	144.03±7.84	<0.01	93.7

The results of manual dexterity test performed on the auto mechanics were indicated in Table 5. The results showed statistically significant differences between manual dexterity criteria of the participants in cold and neutral air conditions.

The prevalence of finger sensation levels of the auto mechanics determined based on the sensory evaluation chart were illustrated in Figure3. Finger sensation disorders prevalence among participants in cold air were calculated 62%, while it was only 4% in neutral air conditions.

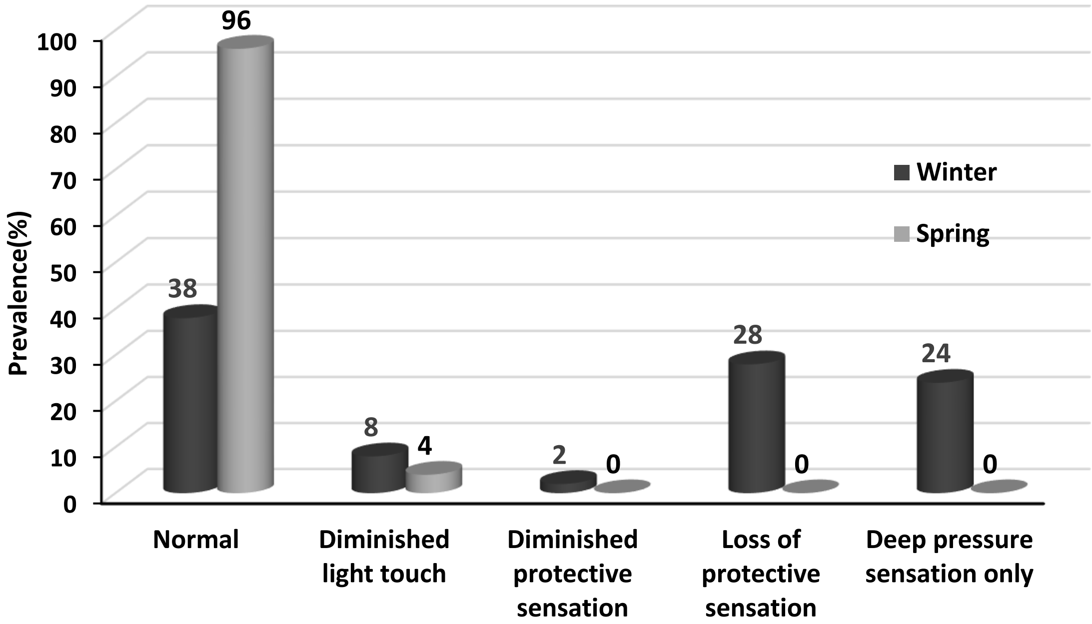


Fig. 3. Participants finger sensation disorders prevalence

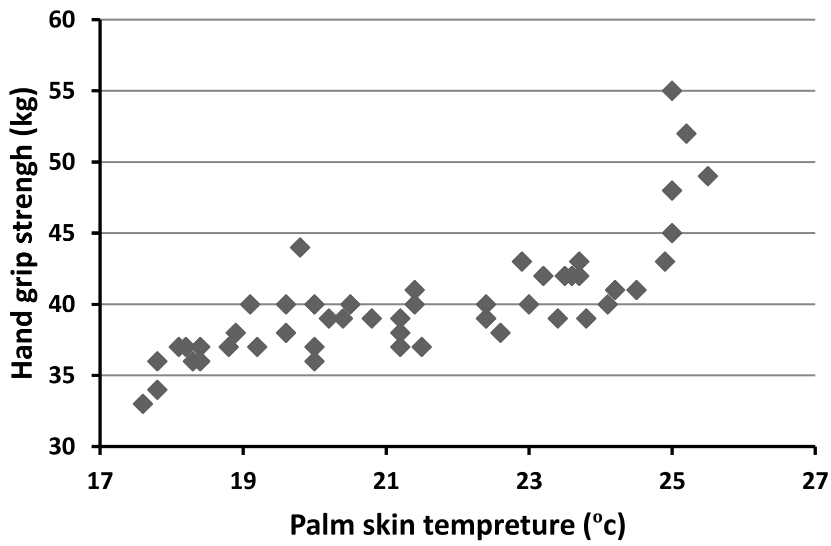


Fig. 4. Palm skin temperature scatter plot in comparison with hand grip strength

The scatter plot of finger skin temperature and its relationship with pinch grip strength were demonstrated in Figure5. As shown, there was a significant positive correlation between finger skin temperature and pinch grip strength ($r=0.79$, $p<0.01$).

The scatter plot of finger skin temperature and its relationship with manual dexterity were illustrated in Figure 6. As shown, there was a significant reverse correlation between finger skin temperature and placing test ($r=-0.80$, $p<0.01$) and turning test ($r=-0.76$, $p<0.01$).

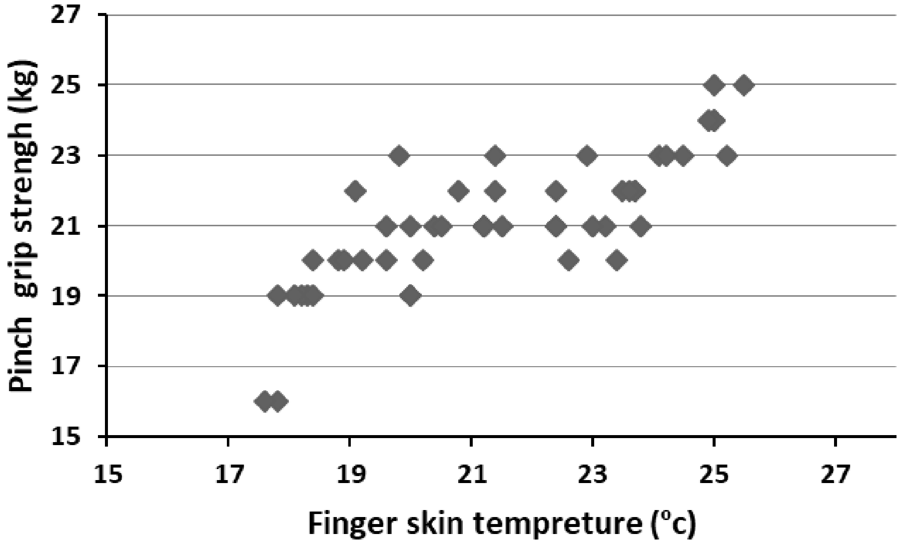
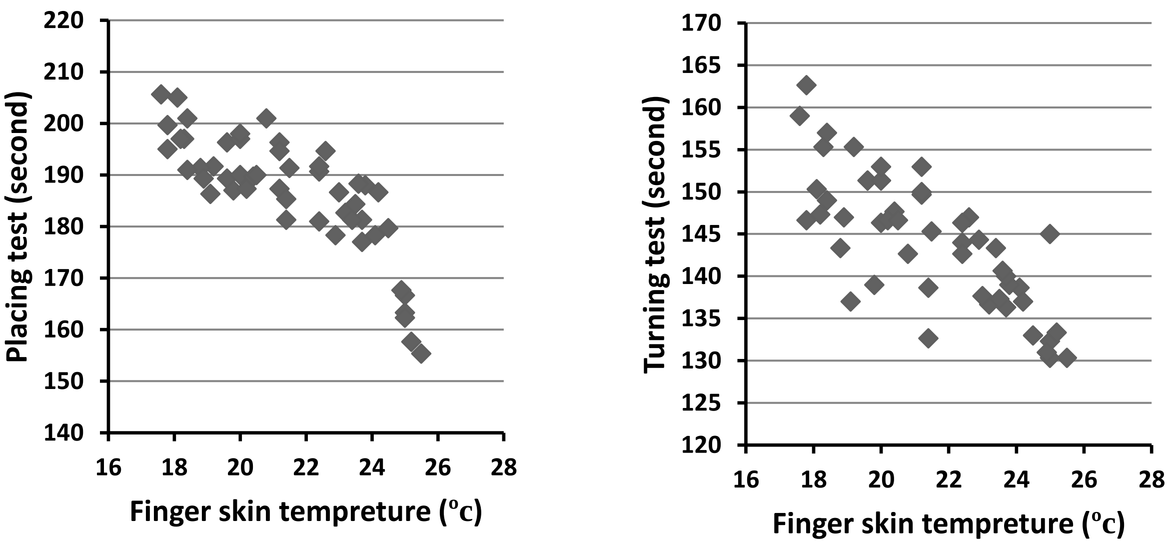


Fig. 5. Finger skin temperature scatter plot in comparison with pinch grip strength

Fig. 6. Finger skin temperature scatter plot in comparison with manual dexterity



The scatter plot of finger sensation level and its relationship with placing test were presented in Figure 7. As shown, there was a significant positive correlation between sensory function and placing test ($r=0.65$, $p<0.01$).

The scatter plot of finger sensation level and its relationship with turning test were demonstrated in Figure 8. As shown, there was a significant positive correlation between sensory function and turning test ($r=0.72$, $p<0.01$).

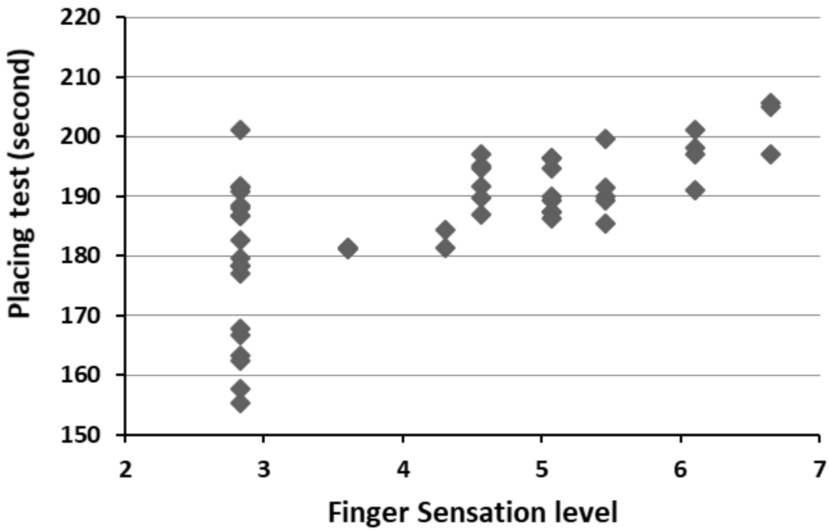


Fig 7. Finger sensation level scatter plot in comparison with placing test

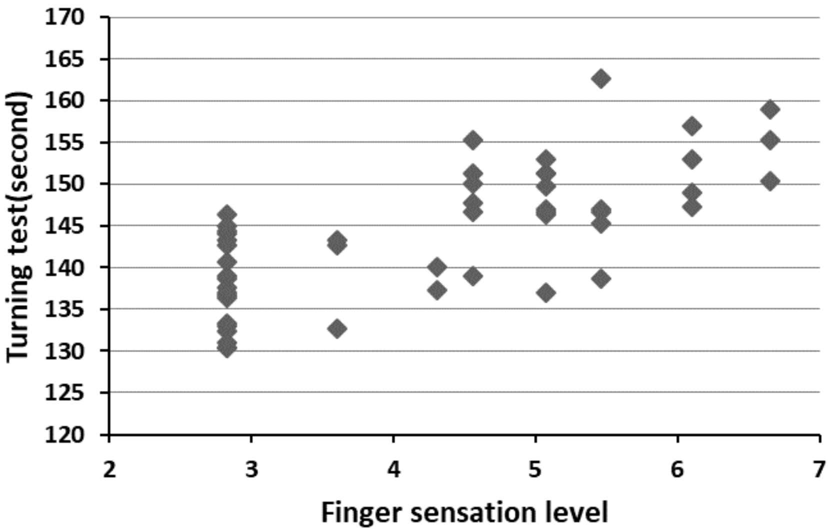


Fig 8. Finger sensation level scatter plot in comparison with turning test

DISCUSSION

There is scarce epidemiological evidence to reach reliable conclusions about the effects of cold air exposure on manual performance of workers working in cold environments. The results of the current study showed that the physiological responses of the auto mechanic workers were influenced by cold air temperature below 0ºC. Moreover, the prevalence of finger sensation disorders in cold air condition was significantly higher than in neutral air condition. Gavhed et al. also showed that the chronic exposure to cold air increased pain and nervous and sensory disorders among 19% of men and 45% of women [24].

The hand and pinch grip strengths of the workers, respectively, decreased by 10.3% and 10.1% in cold air, compared to neutral air. Manual dexterity of auto mechanics also increased from 6.3% to 8.8 % in exposure to cold air, compared to neutral air. The results were in line with the findings of Schiefer et al. study who reported the loss of manual performance at a finger skin temperature of 20–22°C, and a more remarkable loss of performance in finger skin temperature of 15–16°C [25]. Moreover, Dizmen et al. showed that the performance of the subjects measured based on the reaction time and hand dexterity tests were considerably lower at low temperature (10 °C), compared to their performance in high temperatures (20 °C and 30 °C) [26]. Other studies have also reported a reduction in manual dexterity in a local skin temperature of 12 -16oC [16]. Daanen used wind chill equivalent temperature to predict the loss of manual performance in cold exposure time; the results showed that finger dexterity could reduce by 8.9% in –15°C after 25 min of exposure [23]. Wiggen et al. found that exposure to the temperature of –5°C or colder could decrease skin and body temperatures and, consequently, reduce manual performance during light work [11].

There was a significant positive correlation between finger skin temperature and grip strength and manual dexterity. There was also a significant correlation between finger sensory function and manual dexterity. The results confirmed that the decrease in finger skin temperature of auto mechanics impairs manual performance, leading to a lower level of ability to perform a special activity within a defined time, or an increased frequency of human errors during the working time.

Loss of work ability in auto mechanics provides evidence suggesting the need for effective implementation of preventive measures in the mechanic workshops. An experimental study recently showed that 30 min of continuous cycle ergometer and 30 min of intermittent cycle ergometer can enhance finger dexterity performance in the cold air with a dry temperature of 5 °C [27]. Therefore, endogenous heat production through moderate and simple exercise during working activities can improve dexterity performance. According to Flouris et al., exercise can increase the core body temperature at the time of exposure to cold; therefore, manual performance can be enhanced by increasing finger blood flow and consequently, finger skin temperature [28]. As reported by Obrien et al., compared to the bare face, the thermal face protection during cold exposure provides a physiological advantage by warming the finger, increasing the mean skin and core temperatures, and improving thermal comfort [29].

Having considered all above, auto mechanics are recommended to use the simple headband as a face or forehead thermal protection tool because of it improves thermal comfort during cold air exposure. Moreover, it is apparently necessary for workers to work in cold workplaces to undergo a periodical medical check program. Finally, to prevent the negative effects of exposure to cold air, auto mechanics should take frequent short breaks in a warm rest area, use portable heater in their workstation to periodic rewarm their hands, avoid prolonged standing or sitting in the cold air environment, avoid contact of bare skin with cold surfaces (especially metallic tools) below -7°C and wear thinner gloves when performing some simple work as possible. The main objective of the current study was investigating the effect of exposure to cold conditions on performance compared to neutral air. Therefore, in exposure to same cold air condition, the effect of the basic parameters as air velocity on performance can be studied in future researches. Moreover, in current field study, investigation of the effect of different cold exposure categories on performance was not possible. This type of experiment can be performed in a climate chamber with different scenario of cold exposure.

It should be noted that the health risk of cold exposure is also dependent on some behavioral factors such as cigarette smoking, daily diet, and exposure time [30]. The complementary studies can be performed on secondary factors affecting cold tolerance of workers in extremely cold air environments. Some factors such as sex, race, habituation, fitness, and anthropometry that influence cold tolerance can be also studied in future researches.

CONCLUSION

The detailed aspects of human performance during exposure to air cold are not well described yet. Current work discussed the nature and the extended effects of exposure to cold stress on manual performance. During exposure to cold air, handgrip strength and dexterity as the main important criteria affecting auto mechanics' activities were significantly reduced. The findings confirmed that the changes in physiological and sensory functions have significantly reduced the hand working ability of auto mechanics during the cold season. It is recommended that auto mechanics should take short breaks to periodic rewarm their hands and avoid prolonged standing or sitting in cold air. This study can provide empirically helpful information on the manual performance of typical workers exposed to outdoor cold air and also provide a database for further epidemiological researches.

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CONFLICTS OF INTEREST

The authors have no conflict of interests to declare.

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