The Effect of Temperature on Manual Dexterity, Reaction Time, and Optimum Grip-Span

Coskun DIZMEN, Ken S.S. MAN and Alan H.S. CHAN

***Abstract*—Industries such as fish filleting, meat packaging, cold storage and outdoor jobs require workers to work in cold environments. An experiment was conducted to investigate the effect of cold on manual dexterity, reaction time and optimum grip-span. The participants were twelve healthy male university students (median = 20 years). The results showed that performance on the O'Connor dexterity test, stabilimeter and reaction time tests was significantly lower at low temperature (10 °C) compared to performance at higher temperatures (20 °C and 30 °C). Optimum grip-span at 10 °C was narrower than at 20 °C and 30 °C. In conclusion, the performance measures at 10 °C were degraded compared to performance at the higher temperature levels tested. The results of this study on the performance of people in cold environments provide important information for work design in such industries.**

***Index Terms*—Cold immersion, dexterity, grip-span, reaction time, temperature**

I. INTRODUCTION

OCCUPATIONS such as fish filleting, meat packaging [1], cold storage [2] and outdoor jobs [3] require workers to accomplish skilled hand movements while exposed to cold environments. Cold exposure is also encountered in military operations [4] and diverse activities and jobs such as climbing and mountaineering, oil platform work, carpentry, technical maintenance, and polar explorations [5], all of which require a wide variety of hand skills. Past research has shown that prolonged working in extremely cold environments reduces manual dexterity and leads to an increased risk of accidents [2]. Similarly, manual tracking performance decreases in cold temperature [6], and musculoskeletal problems experienced by workers increase under conditions of extreme cold exposure [1].

To alleviate the adverse effect of cold, workers typically wear protective insulating clothing [7]. However extra insulation materials sometimes restrict motion ability, reduce force, power and contraction velocities of muscles and thus reduce performance of workers [8]. It has been shown that the detrimental effect of gloves is sometimes more pronounced than the adverse effect of cold temperatures on human performance [9] – [11]. Nevertheless, it is not possible to avoid working in cold conditions and some workers are regularly exposed to cold work environments. An understanding how cold hinders different skills and various aspects of performance is necessary for work design engineers.

Under the same humidity condition, human beings perceive cold surfaces to be wetter and more slippery than those at room temperature [12]. Carnahan, Dubrowski, and Grierson [13] recently found that people need to apply higher pinch grip forces under cold temperatures in order to feel that they are handling the work safely. For strength under cold conditions, Johnson and Leider [14] and Barnes [15] found there was a decrease in grip strength after prolonged cold water immersion. Vincent and Tipton [16] found that immersion of the hand into 5 °C water decreased the maximum voluntary grip strength for conditions both with and without gloves. Similarly, Chi, Shih, and Chen [17] found that the maximum voluntary contraction (MVC) for grip was lower after immersion in an 11 °C water bath when compared to grip after immersion in a 34 °C bath.

Thus, to sum up, previous research has indicated that in cold temperature conditions, the perceived need for exertion of force to perform a task increases while the ability to exert force decreases. Therefore, it is important to know the value of optimum grip-span to handle the work safely in cold environment.

The optimum grip-span, described as an optimal separation as a function of maximal force output, at a constant temperature has been investigated by a number of ergonomics researchers [18]. Blackwell, Kornatz, and Heath [19] tested grip-spans by using grip circumferences of 10, 13, 16, and 18 cm and found that MVC occurred at a circumference of 16 cm (5.09 cm diameter). Goonetilleke, Hamad, and So [20] claimed that preferred grip-spans vary depending on the size and strength of the hands of the population sampled. They tested grip-spans of 3.5, 4.7, and 5.9 cm using subjective rating and maximum force exertion as determinant of optimum grip-span and it was found that middle span (4.7 cm) was the optimum grip-span for a sample of the Hong Kong Chinese population.

Other researchers have also examined the relationship between grip-span and MVC using similar procedures [21, 22]. However, Eksioglu [18] conducted a comprehensive study where he defined a new dimension, namely, modified thumb crotch length (TCLm), which was defined as "the distance between middle furrow of middle finger and the base of the thumb" and measured the optimum grip-span as a function of TCLm at a temperature of 72 °F (22.2 °C). According to the maximum voluntary isometric grip force (MVGF) results obtained in the [18] study, the optimum grip-span was found as TCLm-2, which is the grip-span 2 cm narrower than the modified thumb crotch length (TCLm).

In previous studies, hand related features such as TCLm [18], grip circumference [19], grip diameter [23] and the hand span (the distance between tips of the thumb and small finger

Manuscript received Oct 16, 2013; revised Dec 23, 2014.
The work described in this paper was fully supported by a grant from City University of Hong (SRG7004250).
Coskun DIZMEN (Email: coskun_dizmen@hotmail.com), Ken S. S. Man (Email: ssman6-c@my.cityu.edu.hk) and Alan H.S. Chan (Email:alan.chan@cityu.edu.hk) are with the Department of Systems Engineering and Engineering Management, City University of Hong Kong, Kowloon Tong, Kowloon, Hong Kong.

when the hand is wide open) [24, 25] have been measured to determine optimum grip-span. However, the effects of ambient factors like temperature have not been analyzed to any great extent yet and this study is aimed at filling this gap in research.

In this study, four hypotheses were proposed to test the effect of temperature on several human abilities. As mentioned above, the effect of temperature on MVC values has been studied by other researchers [16, 26, 17]. However there have been no studies on the effect of temperature on grip-span. Therefore, the first hypothesis was H1: Cold immersion of hands results in a narrower optimum grip-span.

Manipulative movement of humans involves a combination of elemental motions with emphasis on finger and manual dexterity, which are important to the tasks such as watch repair, picking up tiny parts, steadiness in the use of small tools, rapid and precise movements over very short ranges. Chen, et al. [26] analyzed the effect of cold temperature on manual dexterity with a nut loosening test and the Purdue test. Goonetilleke and Hoffmann [6] analyzed manual tracking performance under temperatures ranging from 10 ℃ to 30 ℃. Both studies showed decrease in manual dexterity with temperature decrease. However, Berger, Krul, and Daanen [27] found that results of the Purdue test and other tests are not necessarily in full agreement, therefore, in this study, the O'Connor dexterity test and a test of hand performance on a stabilimeter were used to see if the findings here for these dexterity tests agree with each other and agree with the dexterity findings of other researchers. The second and third hypotheses were thus H2: Cold immersion of hands results in lower O'Connor test results, and H3: Cold immersion of hands results in lower stabilimeter test results. Kauranen and Vanharanta [28] found that cold pack treatment causes delayed simple reaction time because of the decrease in neuromuscular functions. The effect of cold pack treatment and cold water bath immersions on reaction time was expected to be similar, thus here, a cold water bath condition was expected to increase reaction time. Therefore, the fourth hypothesis for this study was H4: Cold immersion results in longer simple reaction time.

II. Method

A. Participants

Twelve self-reported healthy male university students were recruited to participate in this experiment. The ages of the participants ranged from 18 and 24 years (median = 20 years) and eleven were right handed and one left-handed. All of them gave written consent and were informed that they could withdraw from the experiment at any time. The descriptive statistics of the participants' hand dimensions are given in the Table I.

Table I

Descriptive statistics of hand dimensions (cm) of the participants.

Hand Dimension	Average
Hand length	18.97
Grip circumference	16.43
Palm width	8.60
TCLm	7.55

B. Apparatus

The following equipment and facilities were used in this experiment: Takei continuously adjustable dynamometers with an accuracy of ±0.5kgf, Martin type anthropometers, isolated water bath containers, a water proof electronic thermometer with an accuracy of 0.1℃ (Cooper-DPP400W), an infrared camera (FLIR-SC660), an O'Connor dexterity test kit, a Phepple-type stabilimeter, and a Lafayette response time testing machine.

C. Design of Experiment

For determining optimum grip-span, a randomized block design was adopted using maximum voluntary contraction (MVC) values as response and grip-spans (three levels, TCLm-1cm, TCLm-2cm, TCLm-3cm [18]) as treatment, and the participants as blocks. With this arrangement, the different optimum grip-spans were determined at each of four temperature levels (room air temperature and 10 ℃, 20 ℃, and 30 ℃ water baths). For the dexterity and reaction time tests, again a randomized block design was used taking the participants as blocks. However, for these tests the treatment was the water bath temperature levels, and the responses were the number of pins inserted in 45 seconds (for O'Connor test), the distance tracked without touching the surface of the stabilimeter (for stabilimeter test), and the total reaction time for ten sequential stimuli (for Reaction Time Test). In this way, performances at different temperature levels were compared.

D. Procedures

The participants were asked to come to the experiment with a short sleeve T-shirt [17]. Before the experiment started, they were informed about the procedure of the experiment, and, in order to allow the participants familiarize themselves with the equipment and test procedure, a trial practice period was given to them [29]. All the tests were practiced at room air temperature. The mechanism of the dynamometers was explained and participants were allowed to find the best matching points on their hands to the two poles of the dynamometer.

E. Grip-Span Test

Modified thumb crotch length (TCLm) was measured according to the practice of Eksioglu [18]. The grip-spans of the dynamometers were adjusted to the grip-spans of TCLm-1, TCLm-2, and TCLm-3, which were 1, 2, and 3 cm narrower than each participant's modified thumb crotch length (TCLm). The MVC values were collected when the participant was sitting with a right-angled elbow and straight wrist while his arm was supported with a solid object. For each temperature level, each grip-span was tested at least three times. The participants were allowed to take a 1-minute break between two consecutive MVC measurements [24, 25].

F. O'Connor Dexterity Test

The participants were asked to insert as many groups of three pins as they could into the holes of the test board within 45 seconds with their dominant hand from their non-dominant hand side to the dominant hand side (i.e. right handed participants inserted the pins into the board from left to right). They were told that they did not have to pick up pins that fall down [30].

G. Stabilimeter Test

There were three different paths on the stabilimeter: linear, curved, and rectangular. Each path was tested thirty times and the average of these thirty values was used for each path for statistical analysis. The data analyses for linear, curved, and rectangular paths were done separately.

H. Simple Reaction Time Test

Simple visual (light bulb) and auditory (buzzer) reaction times were measured. The order of testing the two types of tests was randomized across participants. Three sets of ten sequential measurements for each stimulus were tested randomly and the average of the thirty data was used in the data analysis. Participants were asked to place their dominant hand behind a line which was 5 cm in front of the 1.4 x 1.0 cm response button and to react as fast as possible when the stimulus was presented. After they pressed the button with their index fingers, they returned their hands to behind the line and another stimulus was presented randomly. This procedure was used in order to make the experiment more realistic because in many practical situations a finger is not placed on a button or key before a signal is presented. The completion of this task thus required not only perceptual skills but also motor skills [28].

I. Water Baths

The air temperature of the laboratory was kept constant at 22 ℃. Before the participants immerse their hands into any one of the water baths up to their elbows, they took the optimum grip-span test at room air temperature with dry hands. Then they performed all the tests denoted above for each of the water bath conditions.

In total, there were three different isolated water bath containers at temperature levels of 10 ℃, 20 ℃, and 30 ℃. The constancy of the temperatures was maintained with ice or hot water; and checked with an electronic thermometer until the finger skin temperatures were in the acceptable range. After immersing in the water bath, the hand was dried with a paper towel and the hand skin temperature was checked with the infrared camera to assure that the finger skin temperature was in the acceptable range of ±1 ℃ of the water bath temperature. However, for 10 ℃ water bath, the finger skin temperature was allowed to go up to 15 ℃ since the recovery of hands were too rapid for that condition.

III. Results

There was some difficulty in recruiting participants for this experiment. Nevertheless, 12 participants were recruited. It seems that other researchers on cold such as Kim, *et al.* [2], Carnahan, *et al.* [13], Oksa, Rintamaki, and Rissanen [31], and Makinen, Gavhed, Holmer, and Rintamaki [32] also had problems and collected data from only 8 participants. Considering these previous four studies only used 8 participants, the sample size of 12 participants here looks better but was nevertheless disappointing. The modified thumb crotch length (TCLm) values for the participants ranged from 7.0 to 8.3 cm (mean = 7.5 cm).

A. Optimum Grip-Span

For all the three water bath and room air temperature levels, ANOVA results showed that grip-span had a significant effect on MVC. For room air temperature (22 ℃) dry hand condition - before any water bath immersion, and 10 ℃ water bath condition, Tukey's test indicated that MVC values for TCLm-2 (the grip-span which was 2 cm narrower than one's modified thumb crotch length) was significantly higher than those for TCLm-1 and TCLm-3. The optimum grip-span, TCLm-2, was found for these two temperature conditions.

For the 20 ℃ and 30 ℃ water bath conditions, Tukey's test results showed that MVC values for TCLm-1 and TCLm-2 were not significantly different while MVC for TCLm-3 was significantly lower than those for TCLm-1 and TCLm-2. Mean MVC value for TCLm-1 was larger than that for TCLm-2. Therefore, the optimum grip-span for 20 ℃ and 30 ℃ water bath conditions, is expected to be larger than TCLm-2. This shows that the optimum grip-span for 20 ℃ and 30 ℃ water bath conditions was larger than that for the room air temperature condition. The optimum grip-span for 10 ℃ water bath condition was smaller than that for the 20 ℃ and 30 ℃ water bath conditions. The MVC values versus grip-span levels for different temperature levels are shown in Figure 1.

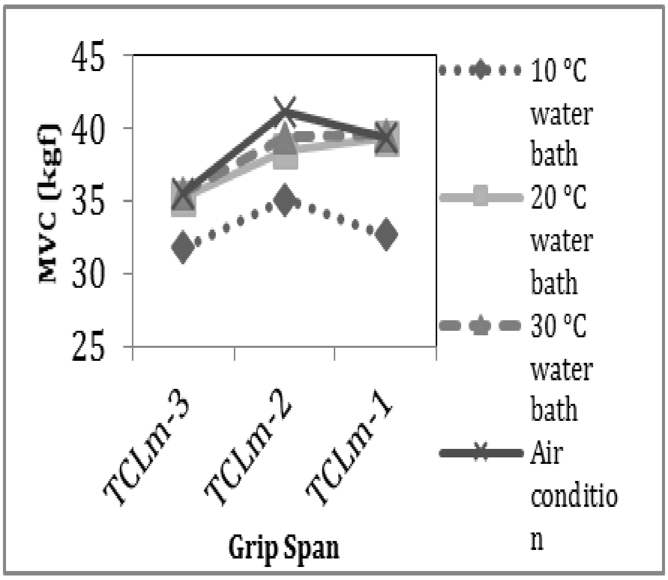

Fig. 1. Effect of grip-span on maximum voluntary contraction (MVC) for different temperature conditions.

B. O'Connor Dexterity Test

ANOVA results showed that temperature has a significant effect on the O'Connor test results ($p < 0.01$). Tukey's test showed that the number of pins inserted for the 10 ℃ water bath condition was significantly lower than number for the 20 ℃ and 30 ℃ conditions. The difference between the number of pins inserted for the 20 ℃ and 30 ℃ conditions was not significant ($p < 0.05$).

C. Stabilitimeter Test

Similar to the results of O'Connor test, ANOVA showed that temperature had a significant effect on the stabilimeter test results ($p < 0.01$). Tukey's test showed that the distance tracked without touching the surface of the machine for 10 ℃ water bath condition was significantly lower than those for 20 ℃ and 30 ℃ water bath conditions and the performance for 20 ℃ and 30 ℃ water bath conditions were not significantly different ($p < 0.05$).

ISBN: 978-988-19253-9-8
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

D. Reaction Time

ANOVA showed that temperature had a significant effect on both the auditory and visual reaction time ($p < 0.01$ and $p < 0.01$, respectively). For both types of stimuli, the results of Tukey's test showed that the difference between reaction times for 20 ℃ and 30 ℃ water bath conditions was not significant whereas the reaction time for 10 ℃ water bath condition was significantly longer than those for 20 ℃ ($p < 0.05$) and 30 ℃ water bath conditions ($p < 0.05$).

IV. Discussion

A. Optimum Grip-Span

Most previous studies on grip-span have used certain constant grip-span levels for all of their participants. Such a methodology ignores the fact that people with different hand dimensions will have different grip spans. In order to take account of this variation, the optimum grip-span can be found as a function of relevant hand dimensions.

A dynamometer with a two-pole design requires the users to support it with the base of their thumb while squeezing it with their fingers. The exact location of the point on the phalanges at which the user gives support varies with the hand dimensions of the user. Therefore, it is difficult to find an exact hand dimension to relate to the optimum grip-span. Under the circumstances, and with the previous application of TCLm, which has been used for measuring the optimum grip-span [18], it was deemed appropriate to use TCLm here.

The results of the Eksioglu [18] study and the before immersion condition at room air temperature for the current study were the same, both found that optimum grip-span was TCLm-2. However, the present study for optimum grip-span at different temperatures is the first such study conducted and will serve as a useful reference for future research in grip-span. The optimum grip-span for 20 ℃ and 30 ℃ water bath conditions was larger than that for the room air temperature condition. This difference could be as a result of an increase of the grasping ability of the participants due to the diffusion of water into the skin of the hand. The wetness of hands may have increased the coefficient of friction giving better grasp ability. The optimum grip-span for 10 ℃ water bath condition was smaller than that for the 20 ℃ and 30 ℃ water bath conditions. This difference seems to be as a result of lower grasping ability in the cold environments. The TCLm method [18] used in this experiment is suitable to test hook grip-span. However, there are some other common grip types used in the industry [33]. Thus, the results of this study should not be generalized to the other grip types (e.g. cylindrical grip) [34].

B. Dexterity Test

Purdue test and manual tracking performance results have been used as the criteria of manual dexterity in the previous research on cold immersion [26, 6] and such studies have provided useful information about the degradation of dexterity performance in cold environments. However, because different tasks require different skills and different muscle involvements, it is necessary to consider a wider range of tests before trying to generalize about the effects of cold upon dexterity tests.

Goonetilleke and Hoffmann [6] used a task which required the participants to draw between two constraining straight lines. This task is quite similar in some ways to the linear path of the stabilimeter test in the current study except that the paths on the stabilimeter become narrower along the direction of travel. Another difference between the current study and that of [6] was that, in addition to a straight path, the stabilimeter tasks here included two additional paths; one curved and one rectangular. The stabilimeter performance levels at all the paths were found degraded at 10 ℃ compared to 20 and 30 ℃, and the effect of cold was found to be more pronounced on the curved and rectangular paths compared to the linear one. The performance at 10 ℃ was lower than that at 20 and 30 ℃ by 20.0% and 22.4% respectively for the linear path, 23.6% and 25.9% lower for curved path respectively and, 34.7% and 37.0% lower respectively for the rectangular path. The effect of cold was more pronounced when the path was more complex.

The stabilimeter test involved overall coordination of the arm muscles and was a test of gross dexterity. However, the current study also employed the O'Connor test which involved fine finger coordination abilities such as pincer grip. Its test results at 10 ℃ were 23.5% lower than at 20 ℃ and 24.6% lower than at 30 ℃.

The coldest condition caused a similar degrading effect on performance levels for the O'Connor test and the curved path of the stabilimeter. However, performance level on the O'Connor test was degraded more than that on the linear path of the stabilimeter but less than that of rectangular path of the stabilimeter. These results make it difficult to generalize as to whether gross dexterity is more affected by cold than fine dexterity, or vice versa. The exact nature of the task and involvement of the precise muscle groups may need to be taken into account in order to get more specific information about the effect of cold on performance.

C. Reaction Time

In this study, reaction time was defined as the time taken to stop the consecutive randomly timed single stimuli with a hand movement 5 cm. The task and the methodology used here were very similar to those of Kauranen and Vanharanta [28], and the results were similar in the finding that cold temperature delayed reactions. The difference between the two studies was the way in which cold temperatures were achieved. Kauranen and Vanharanta [28] used cold packs of -15 to -20 ℃ whereas the current study examined if delayed reactions start at higher temperature (10 or 20 ℃) by inducing the cold via water bath immersion. The results showed that significant delays appeared at the 10 ℃ condition. In the cold pack treatment, the hand gets in contact with the cold via a certain portion of the overall surface. However, cold water bath immersion involves the entire surface of the hand. But regardless of the way of inducing the cold, the reaction time performance dropped with lower temperatures. With the cold water bath immersion method, the reaction time performance reduction is significant at even 10 ℃ which is more common to encounter in the workplaces.

D. Limitations

There are two major limitations that need to be noticed. First, the participants of this study were young students. The findings obtained here may differ with the age characteristics of the participants, and they may not be completely representative of the real work conditions. Second, although some useful findings were obtained in this study and some speculations were provided by the authors, the theoretical reasons for such findings are not available at this stage and

ISBN: 978-988-19253-9-8
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

they need to be given and confirmed by ergonomists with knowledge in physiology and related areas in future.

The findings of this study may not be generalized for the entire human kind because a sample from a different ethnic composition may produce different results [35].

V. CONCLUSION

The objective of this study was to investigate the effect of cold on dexterity, reaction time and optimum grip-span. For this purpose, four hypotheses were set and a series of experiments was conducted on 12 volunteer participants. The results confirmed the asserted hypotheses by showing that narrower optimum grip-span and lower performance in the O'Connor test, stabilimeter test, and reaction time test were obtained at 10 ℃ condition compared to 20 ℃ and 30 ℃ conditions. The results of the study should be useful for situations where cold conditions are required, such as cold storage, fish filleting, meat packaging, military operations and Arctic or Antarctic explorations where narrower optimum grip-span, reduced dexterity, and delayed reactions at cold temperature can lead to an increase in accidents.

ACKNOWLEDGEMENT

The authors would like to thank Dr. Mahmut Eksioglu and Prof. Errol Hoffmann for their valuable comments on the early draft of the manuscript. Thanks are also extended to all the participants for their kindness and patience.

REFERENCES

[1] Piedrahita, H., Punnett, L. and Shahnavaz, H. (2004) Musculoskeletal symptoms in cold exposed and non-cold exposed workers. *International Journal of Industrial Ergonomics*, 34, 271-278.

[2] Kim, T.G., Tochihara, Y., Fujita, M. and Hashiguchi, N. (2007) Physiological responses and performance of loading work in a severely cold environment. *International Journal of Industrial Ergonomics*, 37, 725-732.

[3] Blomkvist, A.C. and Gard, G. (1999) Computer use in cold environments. *Applied Ergonomics*, 31, 239-245.

[4] Jayaswal, R., Sivadas, P. and Mishra S.S. (2001) Health and performance of military personnel in cold climatic environment of the western Himalayas. *Medical Journal Armed Forces India*, 57 (4), 322-325.

[5] Hoffman, R.G. and Wittmers, L.E. (1990) Cold vasodilatation, pain and acclimatization in arctic explorers. *Journal of Wilderness Medicine*, 1 (4), 225-234.

[6] Goonetilleke, R.S. and Hoffmann, E.R. (2009) Hand-skin temperature and tracking performance. *International Journal of Industrial Ergonomics*, 39, 590-595.

[7] Oliveira, A.V.M., Gaspar, A.R. and Quintela, D.A. (2011) Dynamic clothing insulation. Measurements with a thermal manikin operating under the thermal comfort regulation mode. *Applied Ergonomics*, 42, 890-899.

[8] Rogers, W.H. and Noddin, E.M. (1984) Manual performance in the cold with gloves and bare hands. *Perceptual and Motor Skills*, 59, 3-13.

[9] Bishu, R.R., Batra, S., Cochran, D.J. and Riley, M.W. (1987) Glove effect on strength: an investigation of glove attributes, In Proceedings of the 31st Annual Meeting of the Human Factors and Ergonomics Society, Pp. 901–905.

[10] Brajkovic, D., Ducharme, M.B. and Frim, J. (2001) Relationship between body heat content and finger temperature during cold exposure. *Journal of Applied Physiology*, 90, 2445–2452.

[11] Havenith, G. and Vrijkotte, T.G.M. (1993) Effectiveness of personal protective equipment for skin protection while working with pesticides in greenhouses. III Comfort and ergonomics. Report no. IZF-C40. TNO Human Factors Research Institute, Soesterberg, The Netherlands.

[12] Bershansky, I. (1923) Thunberg's illusion. *Journal of Experimental Psychology*, 34, 291–295.

[13] Carnahan, H., Dubrowski, A. and Grierson L.E.M. (2010) Temperature influences both haptic perception and force production when grasping. *International Journal of Industrial Ergonomics*, 40, 55-58.

[14] Johnson, D.J. and Leider, F.E. (1977) Influence of cold bath on maximum handgrip strength. *Perceptual and Motor Skills*, 44, 323-326.

[15] Barnes, W.S. (1983) Effects of heat and cold application on isometric muscular strength. *Perceptual and Motor Skills*, 56, 886.

[16] Vincent, M.J. and Tipton, M.J. (1988) The effects of hand protection and cold immersion on grip strength, In Contemporary Ergonomics 1988, Proc Ergonomics Soc 1988 Ann Conf, Manchester, UK, 11–15 Apr 1988. E.D. Megaw (Ed). Taylor & Francis, London, 1988, Pp. 322–327.

[17] Chi, C.F., Shih, Y.C. and Chen, W.L. (2012) Effect of cold immersion on grip force, EMG, and thermal discomfort. *International Journal of Industrial Ergonomics*, 42, 113-121.

[18] Eksioglu, M. (2004) Relative optimum grip span as a function of hand anthropometry. *International Journal of Industrial Ergonomics*, 34, 1-12.

[19] Blackwell, J.R., Kornatz, K.W. and Heath, E.M. (1999) Effect of grip span on maximal grip force and fatigue of flexor digitorum superficialis. *Applied Ergonomics*, 30 (5), 401-405.

[20] Goonetilleke, R.S., Hamad, B., and So, R.H.Y. (2002) Grip Span and Arm Position Effects on Grip Strength. Available from: http://www.ieem.ust.hk/dfaculty/ravi/papers/aseagrip.pdf [Accessed 15 February 2014].

[21] Petrofsky, J.S., Williams, C., Kamen, G. and Lind, A.R. (1980) The effect of handgrip span on isometric exercise performance. *Ergonomics*, 23 (12), 1129–1135.

[22] Fransson, C., and Winkel, J. (1991) Hand strength: the influence of grip span and grip type. *Ergonomics*, 34 (7), 881–892.

[23] Rossi, J., Berton, E., Grelot, L., Barla, C. and Vigouroux, L. (2012) Characterisation of forces exerted by the entire hand during the power grip: effect of the handle diameter. *Ergonomics*, 55 (6), 682-692.

[24] Ruiz, J.R., Romero, V.E., Ortega, F.B., Sjostrom, M., Castillo, M.J. and Gutierrez, A. (2006) Hand Span Influences Optimal Grip Span in Male and Female Teenagers. *The Journal of Hand Surgery*, 31 (8), 1367-1372.

[25] Romero, V.E., Artero, E.G., Pasias, A.M.S., Gutierrez, A., Castillo, M.J. and Ruiz, J.R. (2008) Hand Span Influences Optimal Grip Span in Boys and Girls Aged 6 to 12 Years. *The Journal of Hand Surgery*, 33 (3), 378-384.

[26] Chen, W.L., Shih, Y.C. and Chi, C.F. (2010) Hand and Finger Dexterity as a Function of Skin Temperature, EMG, and Ambient Condition. *Human Factors*, 52 (3), 426-440.

[27] Berger, M.A.M., Krul, A.J. and Daanen, H.A.M. (2009) Task specificity of finger dexterity tests. *Applied Ergonomics*, 40, 145–147.

[28] Kauranen, K. and Vanharanta, H. (1997) Effects of Hot and Cold Packs on Motor Performance of Normal Hands. *Physiotherapy*, 83 (7), 340-344.

[29] Reddon, J.R., Gill, D.M., Gauk, S.E. and Maerz, A.D. (1988) Purdue pegboard: test-retest estimates. *Perceptual and Motor Skills*, 66, 503-506.

[30] Pennathur, A., Contreras, L.R., Arcaute, K. and Dowling, W. (2003) Manual dexterity of older Mexican American adults: a cross-sectional pilot experimental investigation. *International Journal of Industrial Ergonomics*, 32, 419–431.

[31] Oksa, J., Rintamaki, H. and Rissanen, S. (1996) Recovery of muscular performance by rewarming exercise in the cold. *Human Movement Science*, 15, 591-603.

[32] Makinen, T.T., Gavhed, D., Holmer, I. and Rintamaki, H. (2001) Effects of metabolic rate on thermal responses at different air velocities in -10 ℃. *Comparative Biochemistry and Physiology Part A*, 128, 759-768.

[33] Imrhan, S.N. (2006) Hand grip characteristics and strength. In: Karwowski W, editor. International Encyclopedia of Ergonomics and Human Factors. Volume 1. Boca Raton: Taylor & Francis. p.386.

[34] Wimer, B., Dong, R.G., Welcome, D.E., Warren, C. and McDowell, T.W. (2009) Development of a new dynamometer for measuring grip strength applied on a cylindrical handle. *Medical Engineering Physics*, 31 (6), 695-704.

[35] Dizmen, C. (2012) Hand Anthropometry Analysis and Construction of Regression Models for a Hong Kong Sample, In Proceedings of the International MultiConference of Engineers and Computer Scientists, Pp. 1446–1448.