The Effects of Cold Immersion and Hand Protection on Grip Strength

M. J. VINCENT B.Sc., M.Sc., and
M. J. TIPTON, M.Sc., Ph.D.

The Institute of Naval Medicine, Gosport, Hants, England

VINCENT MJ, TIPTON MJ. *The effects of cold immersion and hand protection on grip strength.* Aviat. Space Environ. Med. 1988; 59:738–41.

The maximal voluntary grip strength (MVGS) of male volunteers was examined following a series of five intermittent 2 min cold water (5°C) immersions of the unprotected hand or forearm. MVGS changes due to wearing a protective glove were also investigated. The surface electrical activity over the hand flexor muscles was recorded, as was the skin temperature of the hand and forearm. MVGS decreased significantly (p<0.01) following hand immersion (16%) and forearm immersion (13%). The majority of these reductions occurred during the first 2-min period of immersion. The effect of wearing a glove after unprotected hand cooling also produced significant (p<0.01) MVGS reductions which averaged 14%. These reductions were in addition to those caused by hand cooling. We conclude that both hand and forearm protection are important for the maintenance of handgrip strength following cold water immersion.

FOLLOWING ACCIDENTAL immersion in cold water, the victim may need all available grip strength to facilitate or enable rescue. Many personal survival systems are activated manually, while the active egress from deep water into a life raft depends heavily on handgrip strength.

It is important, therefore, that individuals accidentally immersed in deep water maintain a functional level of grip strength. A number of authors (5,6,8) have shown that even short-term immersion of the unprotected forearm in cold water produces a fall in tissue temperature and a reduction in the maximal grip strength of subjects. The mechanism behind this reduction is still a matter for debate, while the effect of hand-only cooling on grip strength has received little detailed investigation.

This manuscript was received for review in August 1987. The revised manuscript was accepted for publication in January 1988.

Send reprint requests to M. J. Vincent, who is a Research Officer, Robens Institute, Surrey University, but based at the Institute of Naval Medicine, Gosport, Hants PO12 2DL, England.

Most "immersion suits" include not only arm protection to the wrist but also gloves for hand protection. However, in view of the lack of research into the effects of hand-only cooling on grip strength, the value of such gloves becomes less obvious, particularly considering their detrimental effect on manual dexterity.

This experiment examined the effect of forearm and hand-only cooling on the maximal voluntary grip strength (MVGS) of individuals who were otherwise normothermic; the effect on grip strength of wearing a glove was also investigated.

MATERIALS AND METHODS

Twelve healthy male volunteers between 20 and 42 years old gave their written informed consent to participate. Each subject undertook three series of five intermittent 2-min immersions in stirred water at 5°C. The experimental conditions were:

- Condition A: Unprotected hand-only immersion—maximal voluntary grips performed with bare hand.
- Condition B: Unprotected hand-only immersion—maximal voluntary grips performed with gloved hand.
- Condition C: Unprotected forearm-only immersion—maximal voluntary grips performed with bare hand.

In Conditions A and B, the bare hand was immersed to the level of the styloid process of the ulna. The arm was kept dry using a dry suit sleeve and was insulated with woolen sleeves. In Condition B, a universally sized three-fingered neoprene glove was placed on the subject's hand just prior to the performance of each MVGS. In Condition C, the bare forearm was immersed horizontally to a level 3 cm above the cubital fossa, the hand was kept dry by a watertight wristlet and insulated with a neoprene mitten, which was removed before each maximal voluntary grip was performed.

Before their first experiment, the subjects were allowed to familiarize themselves with the experimental apparatus. In each condition, the MVGS of the dominant arm of the subjects was assessed twice prior to the first immersion period (with gloved hand in Condition B).

In all cases, 2 min were left between successive tests with the same arm; previous work (2) has shown that this period is sufficient to prevent muscular fatigue. Each subject also performed a maximal voluntary grip with his non-dominant hand prior to immersion.

Two minutes after the last pre-immersion assessments of MVGS, each subject immersed his dominant arm in 5°C water for 1 s (momentary immersion) and then performed a maximal voluntary grip. After 45 s the intermittent immersion period began. The five 2-min periods were separated by 45 s, during which the subject removed his arm from the water and performed a grip test. After the last period of immersion, each subject performed a final maximal voluntary grip with each hand. The subjects were seated throughout each experiment and all assessments of MVGS were carried out in air, with the arm of the subjects in a standardised position. Air temperature was maintained at 25°C for all conditions and subjects wore normal clothing. Subjects performed each condition on separate days with the order balanced between subjects.

Variables recorded: a) MVGS was assessed using a hand dynamometer (MIE Medical Research Ltd., England) consisting of two 22-cm-long adjustable arms, which were fixed 5.5 cm apart. Subjects were instructed to grip the dynamometer as quickly and as hard as possible for 5 s. The output of the dynamometer was passed to a digital display. The MVGS of subjects was expressed as a percentage of the mean resting MVGS. b) EMG was recorded with a portable EMG system (Oxford Medical Systems, England). The system has been described in detail elsewhere (3). The surface electrodes were placed over the flexor digitorum superficialis of the dominant arm in a position which anatomical, experimental and palpatory evidence suggested would give the maximal electromyographic signal from this and other hand flexors in the area. The raw EMG signal was rectified to root mean square (R.M.S.) and the peak value associated with each MVGS was expressed as a percentage of the mean value obtained during the resting MVGS. c) Skin temperature was recorded with skin thermistors (EU thermistor probes, Grant Instruments, England) placed on the dominant forearm close to the site of the EMG electrodes, and on the back of the dominant hand. They were secured with waterproof adhesive tape (Setonplast). The thermistors were connected to a 4-channel data logger (Squirrel Data Loggers, Grant Instruments, England) which recorded the skin temperatures every 15 s from the start of the experiment, together with air and water temperature.

Statistical Analysis: A within-subject analysis of variance was performed on the data obtained. With the MVGS and EMG (R.M.S.) data, both the absolute and percentage alterations were examined. The results of these analyses were found to be the same; thus, any levels of significance quoted relate to both the absolute and percentage alterations in these variables. Significant contrasts were further examined with the Scheffes method of multiple comparisons.

RESULTS

Momentary immersion produced significant ($p<0.01$) declines in skin temperature of 4–5°C and small, nonsignificant reductions in MVGS compared with resting values (Fig. 1).

By the end of the intermittent immersions, exposed skin temperatures had decreased by 22–23°C. The majority of these reductions occurred during the first 2-min immersion and were found to be significant ($p<0.01$). Immersing the hand cooled the forearm by 2.6°C, and immersing the forearm cooled the hand by 2.9°C. The effect of removing the immersed limb from the water was to produce a transient increase in the exposed skin temperature of 2–5°C.

Reductions were seen in MVGS in all conditions by the end of the immersions compared with the corresponding resting values. The reductions were: 16% during hand-only immersion, 18% during hand-only immersion with gloved MVGS, and 13% during forearm-only immersion. In all three conditions, only the reductions in MVGS during the first 2-min period of immersion were found to be significant ($p<0.01$). No significant alteration occurred in the MVGS of the non-dominant hand over the experimental period.

Wearing a glove significantly ($p<0.01$) reduced MVGS at rest in air by 16% compared with the hand-only ungloved condition. A glove effect was also present during grip tests following immersion of the bare hand, producing a significantly ($p<0.01$) lower MVGS (average 14%) compared with hand cooling and ungloved MVGS. By the end of cooling, the combined effect of both glove and cooling had produced a 31% reduction in MVGS compared with ungloved resting values (Fig. 1). The mean MVGS and EMG (R.M.S.) data are presented in Table I.

Fig. 2 shows the percentage change in EMG (R.M.S.) activity from baseline resting values for each condition. No significant changes occurred in any of the conditions between rest and momentary immersion, or in the two

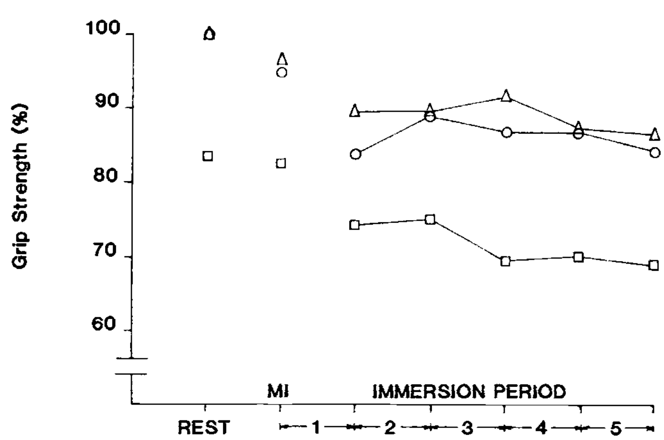

Fig. 1. The mean MVGS during hand immersion (○), hand immersion with gloved maximal voluntary grip (□), forearm immersion (△). MI=Momentary Immersion.

TABLE I. MEAN MVGS (NEWTONS) & EMG (R.M.S., MILLIVOLTS) DATA.

Condition		Rest	MI	Immersion Period				
				1	2	3	4	5
A	MVGS	428	406	358	380	372	370	360
	EMG	622	605	588	615	604	609	609
B	MVGS	359	354	319	321	298	301	295
	EMG	609	606	595	595	586	592	601
C	MVGS	433	419	387	387	397	378	374
	EMG	625	642	629	587	537	504	451

Note: Resting values n=24.

hand-only exposed conditions during the immersion periods.

During forearm-only immersion, the EMG did not fall significantly during the first 2-min period of immersion. Thereafter it fell in a linear fashion reaching 71% of its resting value by the end of the last immersion period. This fall was found to be significant ($p<0.01$). Separate tests showed that it was not due to cooling of any of the immersed parts of the EMG equipment.

DISCUSSION

The results of the present study confirm earlier work which demonstrated that cooling of the forearm produces reductions in the MVGS of individuals (5,6,8). Previous work (6) has shown that no such reductions occur following immersion in water at thermoneutral temperatures.

Agreement has not been reached on the mechanism behind such reductions; many factors which alter with changing muscle temperature could influence the force developed during a maximal voluntary grip. These include metabolic rate, enzyme activity, nerve conduction velocity, calcium and acetylcholine release, series elastic components, and motivation. Clark, Hellon, and Lind (6) reported that arm cooling produced reductions in forearm flexor activity during maximal voluntary grip and suggested that, at temperatures below 27°C, a proportion of the more peripheral fibres of a cooled muscle do not contract due to interference in nervous or neuromuscular transmission.

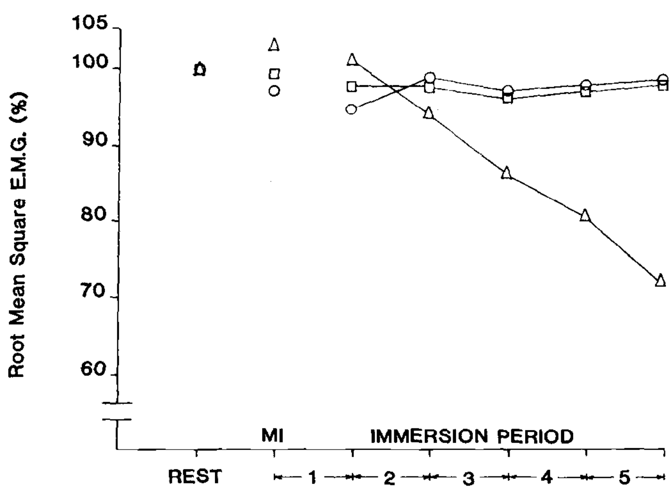

Fig. 2. The mean EMG (R.M.S.) signal during hand immersion (○), hand immersion with gloved maximal voluntary grip (□), and forearm immersion (△). MI=Momentary Immersion.

Vanggaard (18) reported that, after immersion of the forearm in water at 5°C, the motor fibres of the ulnar nerve ceased to conduct at a local skin temperature of 8–10°C.

In the present investigation, the EMG fell during the forearm-only exposed condition over the last four immersion periods. Superficially, this would seem to support the hypothesis that the electrical activity within the muscle was falling during immersion and may have been responsible for the reduction in MVGS observed in this condition. However, examination of Figs. 1 and 2 reveals that during forearm-only immersion, MVGS fell significantly during the first 2-min period of immersion whilst EMG activity was not altered. Also, during the later forearm-only immersions, no further significant reductions occurred in MVGS despite a significant and linear reduction in electrical activity of the flexor muscles.

These discrepancies between the EMG and grip strength data require explanation. Earlier work has shown both a linear (4,7,10,11,13,15) and non-linear relationship (14,19) between EMG and grip strength. A linear relationship between these two variables has primarily been observed during submaximal isometric contractions. In the present experiment, this type of contraction was not undertaken.

In addition, it may be postulated that after 4 min in cold water, the electrical activity of the most superficial muscle fibres was falling due to cooling. As it is these fibres that are primarily responsible for the recorded EMG activity, this also fell. However, these fibres represent only a small percentage of the musculature involved in performing a maximal voluntary grip, and their contribution to MVGS is, therefore, likely to be minimal. Thus, in circumstances where superficial cooling occurs, surface EMG activity may cease to reflect alterations occurring in the muscle as a whole. Its use in such conditions then becomes questionable.

The effect of hand-only immersion has received little detailed investigation. In the present study, the 16% decline in MVGS following hand-only cooling was not associated with a reduction in forearm EMG. During these immersions, observations and subject reports showed that the immersed finger joints became stiff and difficult to manipulate. Hunter, Kerr, and Whillans (12) have suggested that reductions in MVGS may be due to alterations in the viscosity and elastic properties of the joint lubricants and tissues of the hand. However, the results of the present investigation would require almost all of these alterations to occur within the first period of immersion.

The reductions seen in MVGS during the first 2-min period of cold immersion cannot easily be explained by the more frequently proposed mechanisms. Alternative mechanisms, such as cold-induced antagonistic extensor muscle excitation producing a reduction in MVGS (9), therefore warrant further study.

Wearing a glove significantly reduced MVGS in air (16%) and water (14%). This substantiates the earlier findings of Adolfson, Sperling, and Gustaavsson (1). It has been suggested (16) that gloves reduce the grip strength of individuals by disturbing the sensory feedback obtained from beneath the gloved surfaces. The results of the present study suggest that reductions in the MVGS of individuals wearing gloves were not due to alterations in the electrical activity of the forearm flexor musculature, which was maintained at levels similar to those seen during the ungloved hand-only immersion condition.

It would appear that the reductions seen in the MVGS of subjects during the gloved condition were due to some local and specific effect of the glove and its interaction with the wearer.

The results of the present investigation have several practical implications. Exposure of either the forearms or hands to cold has been found to produce significant reductions in MVGS within 2 min of immersion; thus, both of these areas should be protected if such falls are to be avoided. The arms have also been shown to be important areas for the initiation of the potentially dangerous tachycardia and hyperventilation which occur on cold water immersion. Protecting the arms can significantly reduce this response (17). In addition, hand protection helps alleviate the severe discomfort which arises from cooling in these areas (17).

Wearing a glove was found to reduce grip strength by an amount greater than that seen following cold water immersion. Unlike the effect of cooling however, this decrement can be avoided by simply removing the glove. Cold-immersed individuals who have to perform tasks which might require near-maximum levels of grip strength would be well advised to remove their gloves just prior to the performance of such tasks. For the accidentally cold-immersed individual, high levels of grip strength might be required to climb a rope or scramble net, board a life raft, or open and operate a distress flare. This individual is likely to be in a worse state than the present experimental subjects having, most probably, suffered a whole-body continuous immersion.

ACKNOWLEDGMENTS

The authors would like to thank the subjects who volunteered for this study, Surg. Capt. F. Golden, RN, for his advice in the preparation of the manuscript, Mr. T. Beames for his assistance with the experimental work, and the staff of the Institute of Naval Medicine and The Robens Institute for their support.

REFERENCES

1. Adolfson JA, Sperling L, Gustavsson M. Hand protection. In: Arctic underwater operations. Edited by Rey L, ed. London: Graham & Trotman: 1985.
2. Barnes WS, Larson MR. Effects of localized hyper-and hypothermia on maximal isometric gip strength. Am. J. Physi. Med. 1985; 64:305–14.
3. Baty D, Fernandez A, Buckle PW. Recording and analysis of EMG data over extended time periods. In: Progress reports on electronics in medicine and biology. Copeland K, ed. Institution of Electronic and Radio Engineers; 1986.
4. Bigland B, Lippold OCJ. The relationship between force, velocity, and integrated electrical activity in human muscles. J. Physiol 1954; 123:214–24.
5. Clarke DH, Stelmach GE. Muscular fatigue and recovery curve parameters at various temperatures. Res. Q. 1966; 37:468–79.
6. Clarke RSJ, Hellon RF, Lind AR. The duration of sustained contractions of the human forearm at different muscle temperatures. J. Physiol. 1958; 143:454–73.
7. Gans BM, Noordergraaf A. Voluntary skeletal muscles: a unifying theory on the relationship of their electrical and mechanical activitities. Arch. Phys. Med. Rehabil. 1975; 5:194–9.
8. Grose JE. Depression of muscle fatigue curves by heat and cold. Res. Q. 1958; 29:19–31.
9. Hagbarth KE, Finer BL The plasticity of human withdrawal reflexes to noxious skin stimuli in lower limbs. Prog. Brain Res. 1963; 1:65–81.
10. Hof AL, Van Den Berg JW. Linearity between the weighted sum of the EMGs of the human triceps surae and the total torque. J. Biomech. 1977; 10:529–39.
11. Hof AL, Van Den Berg JW. EMG to force processing. J. Biomech. 1981; 14:747–92.
12. Hunter J, Kerr EH, Whillans MG. The relation between joint stiffness upon exposure to cold and the characteristics of synovial fluid. Can. J. Med. Sci. 1952; 30:367–77.
13. Inman VT, Ralston HJ, Saunders JB, De CM, Feinstein B, Wright EW Jr. Relation of human electromyogram to muscular tension. EEG Clin. Neurophys. J. 1952; 4:187–94.
14. Millner-Brown HS, Stein RB. The relation between the surface electromyogram and muscle force. J. Physiol. 1975; 246:549–69.
15. Mote CD Jr., Lee CW. Identification of the human lower extremity dynamics in torsion. J. Biomech. 1982; 15:211–22.
16. Tichauer ER. Biomechanics sustains occupational safety and health. Industrial Engineering 1976; Feb:46–56.
17. Tipton MJ, Golden FSG. The influence of regional insulation on the initial responses to cold immersion. Aviat. Space Environ. Med. 1987; 58:1192–6.
18. Vanggaard L. Physiological reactions to wet-cold. Aviat. Space Environ. Med. 1975; 46:33–6.
19. Zuniga EN, Simons DG. Non-linear relationship between averaged EMG potential and muscle tension in normal subjects. Arch. Phys. Med. Rehabil. 1969:613–20.